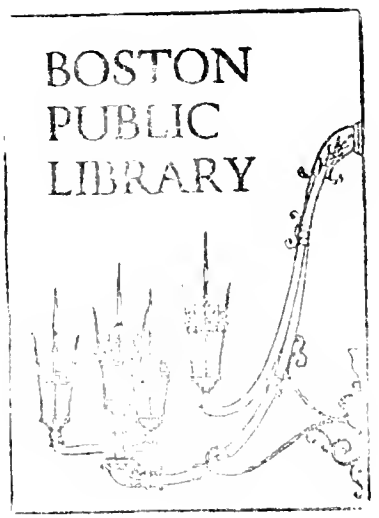
GOVDOC


BOSTON
PUBLIC
LIBRARY

BRA
10-10

IV

Property Of
BOSTON REDEVELOPMENT AUTHORITY
Library

BOSTON PUBLIC LIBRARY

WEATHER DYNAMICS
DIVISION MT. AUBURN RESEARCH ASSOCIATES, INC
385 ELLIOT STREET
NEWTON, MASSACHUSETTS 02164
617-969-7150

A PRELIMINARY WIND EFFECTS STUDY OF THE PARK PLAZA PROJECT, BOSTON, MASSACHUSETTS

By

T. I. McLaren

Submitted to

Saratoga Associates, Inc.
The Arcade
Saratoga Springs, New York 12866

25 March 1975

Park Plaza
M 928
P

A PRELIMINARY WIND EFFECTS STUDY OF THE PARK PLAZA PROJECT, BOSTON, MASSACHUSETTS

By

T. I. McLaren

Weather Dynamics Division
MT. AUBURN RESEARCH ASSOCIATES, INC.
385 Elliot Street
Newton, Massachusetts 02164

For

Saratoga Associates, Inc.
The Arcade
Saratoga Springs, New York 12866

25 March 1975

TABLE OF CONTENTS

	Page
SUMMARY	
1. INTRODUCTION	1
2. WIND CONSIDERATIONS	2
2.1 Effect of Wind on Human Activities	2
2.2 Wind Acceleration by Buildings	3
2.3 Wind Breaks	6
3. TEST FACILITIES AND PROCEDURES	7
3.1 The Wind Tunnel	7
3.2 Flow Velocity Measurements	7
3.3 The Model	8
3.4 Scaling Parameters	8
3.5 Velocity Profiles	10
4. RESULTS	12
4.1 Outline of Study	12
4.2 Test Data	14
4.3 Effect of the Height of the Arlington/Boylston Street Tower	26
4.4 Summary of Results	29
5. CONCLUSIONS	31
APPENDIX A: WINDROSES FOR BOSTON, MASSACHUSETTS	
APPENDIX B: PROBABILITY OF ANNUAL EXTREME WINDS IN BOSTON, MASSACHUSETTS	

LIST OF FIGURES

Figure Number		Page
1	Picture showing air flow around model in MARA Wind Tunnel	5
2	Model on turntable in MARA wind tunnel, showing proposed 6-million square-foot project.	9
3	Schematic plan of the proposed Park Plaza project in downtown Boston.	13
4	Comparative turbulence levels at location I in a NNW wind	23
5	Flow around the northwest corner of the Arlington/Boylston Street tower in a west wind.	27

LIST OF TABLES

Table Number		
1	Wind chill effects relating equivalent chill temperature to mean wind speed	4
2	Data summary of percent occurrence frequencies for wind speed ranges 0-10, 10-20, and >20 mph.	15
3	Percent occurrence frequency data for wind speed ranges 0-10, 10-20, 20-25, 25-30, 35-40, 40-50, and >50 mph.	16
4	Acceleration factors, V/V_{33}, measured at locations N, I, J, and B for various heights of the Arlington/Boylston Street Tower	28

SUMMARY OF RESULTS

A wind tunnel study was carried out to examine pedestrian level wind effects associated with the proposed Park Plaza development. Wind velocity measurements were made at fourteen locations near the project site and data was taken for the present-day (1975) site and for a six million square-foot project development.

The data generated in this wind tunnel study provide information on levels of wind activity at specific locations, in addition to indicating the approximate range on the Public Garden within which wind conditions will be affected by the proposed development. At locations A, C, D, and E on the Boston Public Garden and Common (see Fig. 3), the changes in average wind conditions are relatively small. At A, C, and E there is a general increase in wind speeds, while at D there is an overall reduction in wind speeds. The most severe changes in wind speeds on the Garden occur near location B. Here the effects of the Arlington/ Boylston Street tower are clearly evident in the enhancement of ground level wind speeds. Table 4 illustrates the dependence of the fastest wind speeds at this location on the height of the adjacent tower building.

Wind speeds on the Boylston Street sidewalk at locations F and G are increased as a result of the new development. In general terms, the occurrence frequencies of all wind speeds over 10 mph are increased from 22% to 31% at F, and from 17% to 31% at G by the new development. This is at best undesirable, and will detract from the potential of these locations for window shopping and general pedestrian traffic. Since the primary concern at these locations is for the pedestrian environment on the sidewalk, it is suggested that final designs should include protective facilities such as canopies or enclosed or recessed walkways.

The locations found to incur the worst wind conditions near the new development are clearly those adjacent to the 450-foot tower at the intersection of Arlington and Boylston Streets. At test locations H, I, J, and N substantial increases were measured in the occurrence frequency

of faster wind speeds. Acceleration factors V/V_{33}, between 1.5 and 2.1 were measured at those locations. Thus 30 mph wind speeds at Logan could produce ground level wind speeds at these locations between 45 and 63 mph. These are definitely hazardous to pedestrians and the liklihood exists that people could be blown over by such wind speeds. Conditions at these locations are severe because of the complete exposure of a tall building to the prevailing westerly winds. Additional tests were carried out for locations, N, I, J, and B to examine the effects of the tower height on the fastest wind speeds measured at these locations. The results are presented in Table 4. They show how the wind accelerations are reduced as the height of the tower is reduced. If the tower height is fixed at 450 feet, then detailed testing will be required to examine the details of street level design needed to protect pedestrians from frequently unpleasant and dangerous winds.

On Stuart Street sidewalk wind levels at K were improved by the new development, but at L and M wind conditions will be somewhat less attractive than on the Boylston Street sidewalk at F and G. Consideration should be given to pedestrian protection in the form of canopies or enclosed arcades to enhance Stuart Street as an attractive pedestrian area.

1. INTRODUCTION

This report presents the results of a wind tunnel study of pedestrian level wind effects at locations near the proposed Park Plaza redevelopment project in Boston, Massachusetts. The purpose of the study was to compare levels of wind activity (frequency of occurrence of various wind speed ranges) for the present-day site with those prevailing after the project has been built. To this end, velocity measurements were made at fourteen locations on a wind tunnel model for the present-day site, and at the same fourteen locations with a model of the maximum density development envisaged for the area. These two cases are expected to span the range of possible impact of the project on the area.

The fourteen test locations were selected

(1) in anticipation of areas most likely to incur high levels of wind activity,
(2) areas subject to heavy pedestrian usage,
(3) areas on the Garden and Common most likely to be affected by the project.

The test locations were in general outside the project site, to define the impact of the development on the area. No tests were made on wind levels within the site area, and it is anticipated that these will be carried out when the project planning has evolved to a more specific design.

Thin film anemometers were used to measure air speeds at the test locations on the wind tunnel model at a height equivalent to ten feet above ground. The statistical distribution of wind speeds and directions incident on the site area were calculated from the National Weather Bureau records for Logan Airport.. This, combined with the wind tunnel test data, allowed us to preduce the occurrence frequency of various wind speed ranges at approximately ten feet above ground level.

Windrose presentations to illustrate the general distribution of wind direction and speeds in the Boston area are presented as Appendix A to this report.

2. WIND CONSIDERATIONS

2.1 Effect of Wind on Human Activities

The degree to which wind degrades the value of a given location is not simply a function of wind speed. It depends on temperature and precipitation conditions as well as the type of activity intended for the area. For example, a sheltered reading or meeting area would be severely degraded by winds which would be tolerable on a street.

There is little quantitative information available on the effects of various wind speeds on people. Pedestrian level winds near buildings involve the phenomenon of vortex shedding which is characterized by a high degree of turbulence, or "gustiness". This is illustrated by Fig. 4 of Section 4. As a rule of thumb, peak gust speeds may reach 1½ to 2 times the mean speed, although it is not adequately known how to relate the frequency and magnitude of the fastest gusts to mean wind speeds under these conditions. For the purposes of this study we have summarized the velocity data under three fairly broad ranges of mean wind speeds which provide guidance in estimating the impact of winds on people near the project area. The 0-10 mph range is the condition most commonly encountered on city streets. It is a non-problem, where people are generally unaware of wind action. The 10-20 mph mean speed range may be looked on as acceptable, though it can frequently be undesirable. For example in this speed range, wind chill effects become important (see Table 1), papers and hairstyles may be blown, and the operation of umbrellas can cause difficulty. There is a positive side too. Sitting areas may be enhanced on hot humid days by the pleasant cooling effects of the increased winds, though eventually the benefits can be offset by the buffetting of faster wind speeds.

There is clearly no sharp transition at 20 mph, but mean speeds over 20 mph can be classified as being in the Damage Range. In this category, doors, plantings, and outdoor signs may give trouble. Umbrellas and the carrying of large objects or packages become difficult, and pedestrians may experience problems in walking steadily. This speed range is generally undesirable.

The question of what wind speed will blow people over does not have a simple answer. Depending on a normal physique, a person may stand up in a steady wind speed in excess of 60 mph. However, an intermittent wind of lower mean speed can blow the same person down. In addition to the peak gust velocity attained, other important parameters include the risetime and the duration of the gust, the state of preparedness of the person involved, and the individual's physical capabilities.

Without discussing these varying and inadequately defined parameters, workers in England and Australia have suggested that wind gusts reaching 50 mph may knock a person down. If one accepts this, then a location near a building subjected to mean wind speeds greater than about 30-35 mph may cause people to be blown over.

It is emphasized that these figures can only be looked on as estimates in the absence of adequate field data, but they do represent the best guidelines currently available.

In addition to the summary data presented in Table 2, Table 3 provides the breakdown of occurrence frequencies for wind speeds over 20 mph in 5 mph incremental ranges, i.e. 20-25, 25-30, 30-35 mph, etc.

2.2 Wind Acceleration By Buildings

A major contribution to the wind problems encountered by people arises from the way a building deflects or "pulls down" faster speed winds from a greater height. Figure 1 illustrates this effect. The picture shows a rectangular block model (Height : Width ≈ 1) in the MARA wind tunnel. The air flow is from right to left, and the white streaks show the paths of bubbles which follow the air flow. Air is seen to be deflected downward in front of the building from a point (in this case) about one-half the building height. It is this interaction between a building and the velocity profile in the earth's boundary layer that is primarily responsible for many of the pedestrian level wind problems associated with "tall" buildings.

TABLE 1

WIND CHILL EFFECTS RELATING EQUIVALENT
CHILL TEMPERATURE TO MEAN WIND SPEED

Wind speed (mph)	Local Temperature (^{o}F)										
	32	23	14	5	-4	-13	-22	-31	-40	-49	-58
	Equivalent temperature (^{o}F)										
Calm	32	23	14	5	-4	-13	-22	-31	-40	-49	-58
5	29	20	10	1	-9	-18	-28	-37	-47	-56	-65
10	18	7	-4	-15	-26	-37	-48	-59	-70	-81	-92
15	13	-1	-13	-25	-37	-49	-61	-73	-85	-97	-109
20	7	-6	-19	-32	-44	-57	-70	-83	-90	-109	-121
25	3	-10	-24	-37	-50	-64	-77	-90	-104	-117	-130
30	1	-13	-27	-41	-54	-68	-82	-97	-109	-123	-137
35	-1	-15	-20	-43	-57	-71	-85	-99	-113	-127	-142
40	-3	-17	-31	-45	-59	-74	-87	-102	-116	-131	-145
45	-3	-18	-32	-46	-61	-75	-89	-104	-118	-132	-147
50	-4	-18	-33	-47	-62	-76	-91	-105	-120	-134	-148
	Little danger for properly clothed persons		Considerable danger			Very great danger					

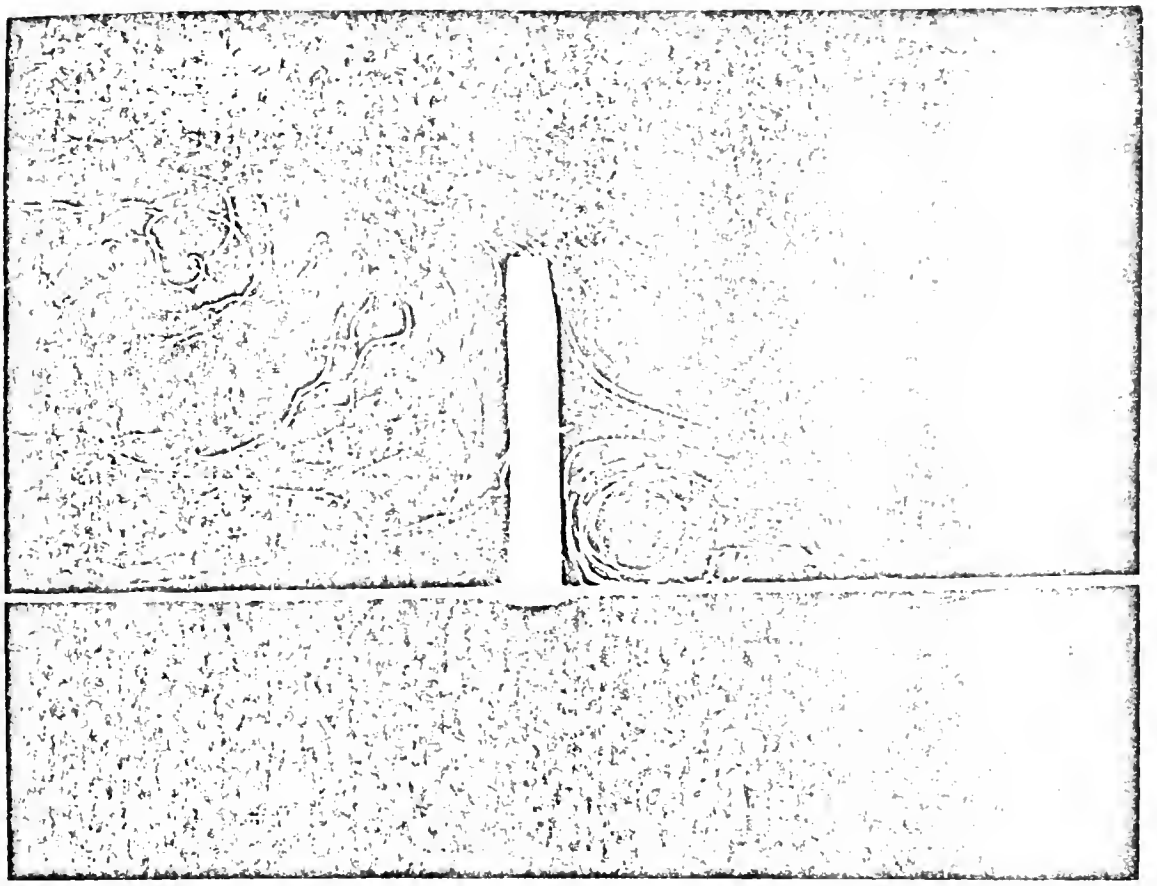


FIGURE 1

The picture shows a rectangular block model (Height:Width = 1) in the MARA wind tunnel. The air flow is from right to left and camera exposure time 0.5 secs. The white streaks show the paths of the helium-filled soap bubbles which follow the air flow. Note how the air is deflected downward in front of the building from a point (in this case) about one-half the building height. It forms a standing vortex pattern in front of the building which is characterized by a relatively high speed circulating air flow.

In addition, wind acceleration close to ground level can occur from geometric focusing effects due to the buildings, as when the wind is forced through a convergent passage between buildings, or through an underpass, or escapes around the corner of buildings.

2.3 Wind Breaks

There are a number of ways of alleviating wind problems near ground level. Trees, sculptures, and covered walkways can provide effective wind breaks as well as the more obvious walls and screens which may be made of glass, wood, or concrete. Where horizontal wind speeds present problems near ground level, these wind breaks can greatly facilitate the passage of people in and out of buildings and alleviate their discomfort in other areas subject to appreciate pedestrian activity.

Winds flowing down the vertical face of tall buildings to ground level frequently cause the most wind problems at head height. These downward deflected winds are best mitigated by canopy projections, or in severe cases by covered areas, top and sides, which prevent any wind movement at an entrance or walkway near the bottom of a tall building. Such areas take the form of vestibules or covered arcades.

3. TEST FACILITIES AND PROCEDURES

3.1 The Wind Tunnel

The Mt. Auburn Research Associates' low speed wind tunnel is 36 feet long, 8 feet wide, and 6 feet high. It was designed specifically to test models of buildings and complexes for wind problems produced by the interaction of buildings with the natural winds. The effects of downdrag by tall buildings, vortex shedding, and enhanced flow velocities through underpass regions are all readily detectable in the tunnel and may be quantitatively assessed. Air is drawn through the tunnel by four adjustable-speed propellors as the downstream end; the flow velocity is variable up to 10 feet per second.

3.2 Flow Velocity Measurements

Local air flow velocities in the tunnel are measured using hot film anemometers. Signals from the thin film sensors are electronically linearized and fed into a digital voltmeter. The output from the digital voltmeter is fed into a Wang 720 programmable calculator which automatically averages 500 readings at a sampling rate of six readings per second. A printout is obtained of the mean velocity and the standard deviation for each test location.

All pedestrian level velocity measurements were referenced to the air velocity at a scaled height of 500 feet, approximately the height of the tallest building in the project area. It is assumed that wind directions and speeds at this height are similar to those at 500 feet elevation at Logan Airport. Occurrence frequencies of wind speeds and directions for 500 feet at Logan are calculated from the Weather Bureau records using Eq. (2), below.

3.3 The Model

A 1" = 40' scale model of the site and surrounding area was provided by the Boston Redevelopment Authority for the wind tunnel test program. The area modelled fitted on the 8-foot diameter turntable in the wind tunnel, representing a diameter of approximately three-quarters of a mile on site. Figure 2 shows the model located in the tunnel, viewing the project from across the Boston Public Garden.

The project portion of the model was replaceable to enable comparative tests to be made on the present-day area and a maximum density (six million square feet) development. In a test sequence, the required wind direction was obtained by orienting the wind tunnel turntable, the anemometer was set at the test location, and data was recorded sequentially for the two model configurations.

3.4 Scaling Parameters

Since effects of atmospheric stability and thermal buoyancy are not of interest to the present study, the significant scaling parameter to be considered for the wind tunnel testing is the Reynolds number, R_e.

$$R_e = \frac{UL}{\nu}$$

where U = mean flow velocity

L = a characteristic dimension (taken as a building width)

ν = kinematic viscosity of air

For blunt objects such as buildings, or their block models in the wind tunnel tests, the requirements for exact scaling of the Reynolds number can be relaxed. The air flow around such a body is found to be similar for values of Reynolds number in the range $500 \leq R_e \leq 2 \times 10^5$. This condition is easily satisfied in the MARA wind tunnel where Reynolds number values are typically 10^4.

FIGURE 2. The model on the turntable in the MARA wind tunnel, showing the proposed 6-million square-foot project. View is from across the Boston Common.

3.5 Velocity Profiles

Velocity profiles in the MARA wind tunnel are scaled to simulate the appropriate atmospheric profiles by the use of screens and grids at the entrance end of the wind tunnel. A series of spaced, fine mesh screens are used to filter out the larger eddies which can be associated with open circuit wind tunnels. Then with a uniform velocity flow entering the tunnel from the sequence of screens, the required vertical profile of velocity is produced by a series of horizontal slats across the tunnel. With smaller separations between slats closer to the tunnel floor, the lower level air speed is reduced. By adjustment of the relative slat separations, the required vertical profile is produced in the tunnel flow.

It has been reported by Brook (1972)[1] that atmospheric turbulence levels in an urban area are dominated by the mechanical turbulence generated by the buildings themselves. In the present study, the effects of ambient air turbulence are not of major importance, but the level of turbulence upstream of our test section was adjusted to a value appropriate to that measured by Brook. Turbulence levels in the tunnel can be controlled by the introduction of additional obstructions upstream of the model. The size of the horizontal slats used to generate the vertical velocity profile also contribute to the upstream turbulence level. In the study reported here, the slat size was adjusted such that the ratio of Standard Deviation : Mean Air Velocity in the upstream flow was less than 5%, which is characteristic of the measurements made by Brook[1].

The variation of air velocity as a function of altitude varies depending on the terrain. It is generally assumed that the variation of velocity with height can be described by a power law dependence as suggested by Davenport[2]

---

1. R. R. Brook, "The Measurement of Turbulence in a City Environment", J. Appl. Meteorology 11, 443 (1972).

2. A. G. Davenport, "The Relationship of Wind Structure to Wind Loading", Symposium at National Physical Laboratory, England, on Wind Effects on Buildings and Structures, Vol. 1, p. 54 (1963).

$$\frac{\overline{V}_z}{\overline{V}_o} = \left(\frac{z}{z_o}\right)^{1/n} \qquad (1)$$

where $\overline{V}_z$ is the mean horizontal wind velocity at height z, $\overline{V}_o$ is the mean velocity at the reference (free stream) altitude, z_o. The value of the exponent n depends on the roughness of terrain and surface features of the area being considered. Typical values of n vary from 2.5 in a high-rise urban center area to 7 in an exposed, smooth terrain. A value of n=3.5 (1/n = 0.28) was selected as the most appropriate for the present study).

This value was used to estimate the wind speeds occurring at Logan Airport from the Weather Bureau data recorded at 33 feet, from

$$\frac{\overline{V}_{ref}}{\overline{V}_{33}} = \left(\frac{z_{ref}}{33}\right)^{0.28} \qquad (2)$$

The 0.28 power law exponent is deemed to be appropriate for the Logan Airport data since, although the site is exposed to the ocean (suggesting n ≈ 6 or 7), the prevailing winds are westerly from across the Greater Boston area (suggesting n ≈ 3 or 4).

The thin film anemometers and linearizer system were calibrated using a pitot-static tube combined with a high sensitivity differential pressure transducer. Horizontal profiles of the tunnel velocity were checked to ensure that the wind tunnel flow onto the model was well behaved and self consistent. Velocity deviations within the center six feet of the tunnel flow were typically ± 2%.

4. RESULTS

4.1 Outline of Study

An analysis was conducted of the distribution of wind speeds and directions to be expected in the vicinity of the Park Plaza development. Due to the short time scale available for this study, there was no opportunity for recording on-site wind data. Thus predictions of the local climatology were based on 10-year (1951-1960) averages of the National Weather Bureau records for Logan Airport, about two miles northeast of the site area. It is expected that these provide an adequate guide for estimating wind conditions at the site area.

Occurrence probabilities of wind directions and speeds are presented in windrose form in Appendix A. Wind speed probabilities are presented in five ranges, namely, 0-7, 8-12, 13-18, 19-24, $\geq$ 25 mph. Appendix B presents extreme wind probability estimates for Boston for 25, 50, 100, and 200 year intervals.

The major portion of the study comprised a program of wind tunnel testing, carried out to examine pedestrian level wind effects in the vicinity of the Park Plaza project. Two series of tests were conducted: (1) with a model of the present-day (1975) area, and (2) with a model of a maximun density (6 million squre feet) development on the project site.

Tests were carried out in the MARA wind tunnel for 16 incident wind directions, i.e., N, NNE, NE, ENE, etc. Measurements were made of local air velocities at ten feet above ground using thin film anemometers, and each measurement was referenced to the incident air velocity at a height of 500 feet upwind of the site area. Probabilities for occurrence of incident wind speeds and directions were based on the Weather Bureau records for Logan Airport.

Measurements were made at 14 locations around the project area as indicated on Fig. 3. At each location an "acceleration factor", V/V_{ref}, was measured for each of the 16 wind directions. An in-house

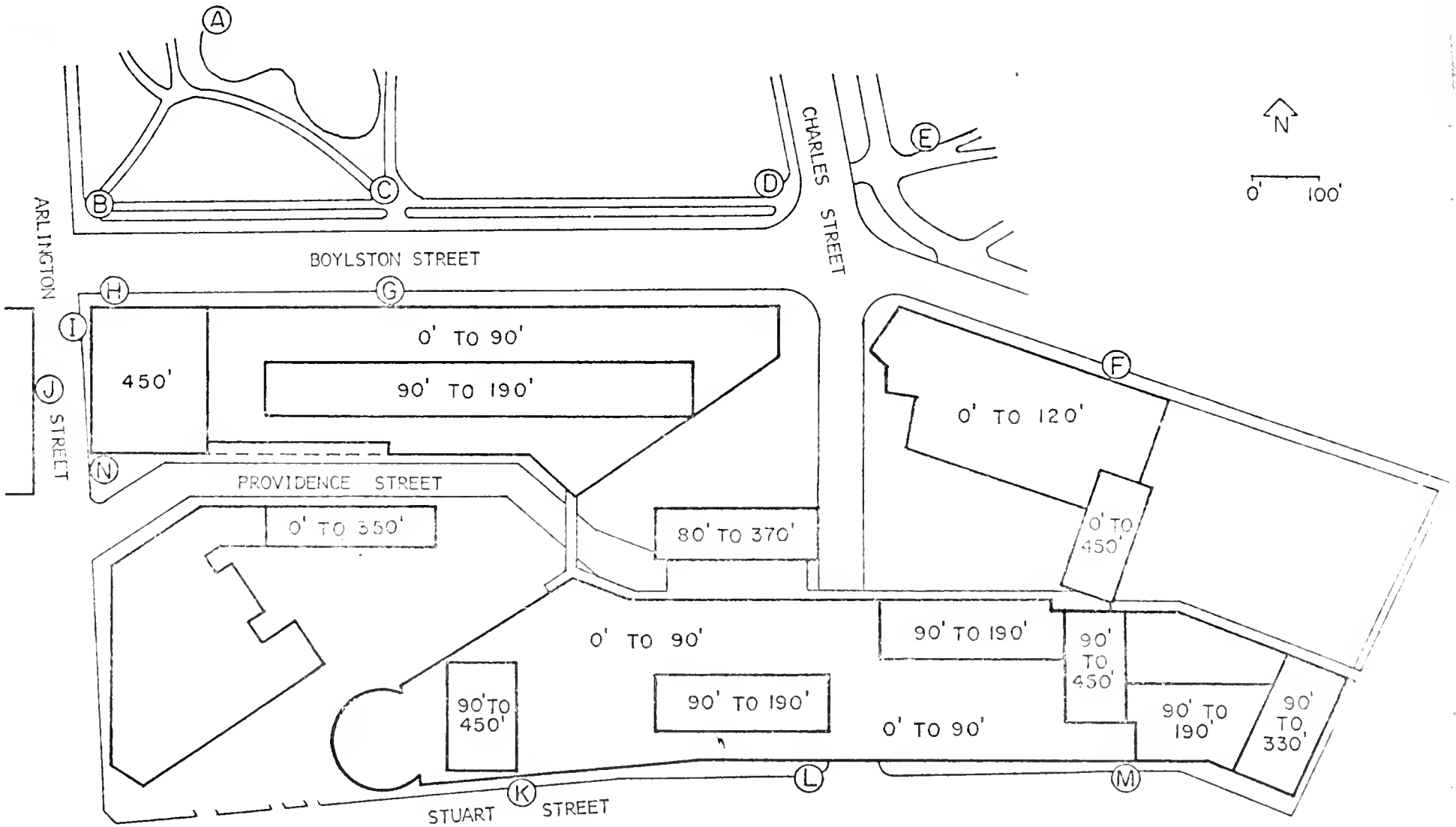


FIGURE 3. Schematic plan of the proposed Park Plaza project in downtown Boston. The buildings shown here represent a six-million square-foot development, the maximum envisaged for the site. The 14 test locations used in the wind tunnel study are labelled (A) through (N).

computer program then combined these acceleration factors with the occurrence frequency of various wind speed ranges for each specific direction. The program output identifies the total occurrence frequency of wind speeds at each location in speed ranges 0-10, 10-20, 20-25, 25-30, 30-35, 35-40, 40-50, and > 50 mph.

The output data is presented in detail in Table 3. Table 2 gives a summary showing occurrence frequencies condensed into three ranges, 0-10, 10-20, and over 20 mph, for easier assimilation. A discussion of the data follows below. Included in the discussion of conditions for each location is a value of maximum acceleration factor, V/V_{33}, for that location. This identifies the maximum velocity measured there as a function of the wind speed at Logan Airport where data is recorded 33 feet above ground. For example a test location with a measured acceleration factor of 0.6 in a WNW wind will experience 0.6x40 = 24 mph wind speeds when 40 mph winds are recorded from the WNW at Logan Airport. In typical urban locations where buildings are not exerting a dominant influence on the local wind speeds, the acceleration factors appropriate to the measurements made in this study would be expected to be less than or equal to about 0.8.

For comparison, data from a previous study in this laboratory has been included in Tables 2 and 3 for wind activity levels at the northeast corner of the Boston Company building, a well-known landmark in the Government Center area of Boston.

4.2 Test Data

The test locations are identified in the schematic map in Fig. 3. The data is presented for each location in terms of percent occurrence frequencies for various wind speed ranges. For example 20% frequency in the 10-20 mph range indicates that wind speeds will be between 10 and 20 mph on an average of 20% of the time or about six days per month. On Tables 2 and 3 subscript "1" refers to present-day site, and subscript "2" refers to the site after the proposed 6-million square-foot development

TABLE 2

DATA SUMMARY OF PERCENT OCCURRENCE FREQUENCIES FOR WIND SPEED RANGES 0-10, 10-20, AND >20 mph

	mph				mph		
Location	0-10 (%)	10-20 (%)	> 20 (%)	Location	0-10 (%)	10-20 (%)	> 20 (%)
A_1	68.3	25.9	5.8	I_1	89.5	9.4	1.1
A_2	58.2	35.5	6.2	I_2	56.5	30.3	13.2
B_1	81.4	16.3	2.3	J_1	85.0	11.4	3.6
B_2	53.9	35.0	11.1	J_2	55.5	31.3	13.2
C_1	76.0	20.2	3.8	K_1	60.0	29.3	10.7
C_2	69.3	27.3	3.4	K_2	74.7	21.7	3.6
D_1	62.0	31.4	6.6	L_1	65.0	31.1	3.9
D_2	72.5	23.7	3.8	L_2	57.7	32.5	9.9
E_1	68.3	26.3	5.4	M_1	76.4	19.2	4.4
E_2	58.5	34.7	6.8	M_2	56.6	37.7	7.7
F_1	78.3	18.6	3.1	N_1	82.7	14.8	2.5
F_2	68.7	25.2	6.1	N_2	65.0	22.2	12.8
G_1	83.2	14.5	2.3	$(H/I)_1$	81.2	15.2	3.6
G_2	68.6	24.4	7.0	$(H/I)_2$	42.1	38.4	19.5
H_1	83.4	13.0	3.6	NE corner of Boston Co. Bldg.	54.0	34.9	11.1
H_2	62.1	29.0	8.9				

Suffix "1" refers to present-day site.

Suffix "2" refers to developed site.

TABLE 3

PERCENT OCCURRENCE FREQUENCY DATA FOR WIND SPEED RANGES
0-10, 10-20, 20-25, 25-30, 30-35, 35-40, 40-50, and >50 mph

Location	mph							
	0-10 (%)	10-20 (%)	20-25 (%)	25-30 (%)	30-35 (%)	35-40 (%)	40-50 (%)	>50 (%)
A_1	68.3	25.9	3.0	1.3	0.5	0.3	0.3	0.4
A_2	58.2	35.5	3.4	0.9	0.7	0.4	0.3	0.5
B_1	81.4	16.3	1.1	0.5	0.3	0.1	0.2	0.1
B_2	53.9	35.0	6.2	2.3	0.9	0.6	0.5	0.6
C_1	76.0	20.2	2.0	1.0	0.2	0.2	0.2	0.2
C_2	69.3	27.3	1.7	0.7	0.4	0.2	0.2	0.2
D_1	62.0	31.4	3.3	1.7	0.6	0.3	0.3	0.4
D_2	72.5	23.7	2.2	0.5	0.4	0.2	0.3	0.2
E_1	68.3	26.3	2.8	1.4	0.5	0.2	0.3	0.2
E_2	58.5	34.7	3.6	1.5	0.7	0.4	0.3	0.3
F_1	78.3	18.6	1.7	0.5	0.3	0.2	0.1	0.3
F_2	68.7	25.2	3.5	0.8	0.5	0.4	0.5	0.4
G_1	83.2	14.5	1.5	0.3	0.2	0.1	0.1	0.1
G_2	68.6	24.4	3.3	1.8	0.9	0.5	0.3	0.2
H_1	83.4	13.0	2.0	0.7	0.3	0.2	0.2	0.2
H_2	62.1	29.0	4.4	1.8	1.0	0.4	0.6	0.7

(continued)

TABLE 3 (continued)

Location	mph 0-10 (%)	10-20 (%)	20-25 (%)	25-30 (%)	30-35 (%)	35-40 (%)	40-50 (%)	>50 (%)
I_1	89.5	9.4	0.8	0.2	0.1	+	+	0
I_2	56.5	30.3	5.7	3.1	1.9	0.9	0.9	0.7
J_1	85.0	11.4	1.9	1.0	0.4	0.1	0.1	0.1
J_2	55.5	31.3	6.5	3.2	1.5	0.4	0.7	0.9
K_1	60.0	29.3	5.6	2.0	0.8	0.6	0.8	0.9
K_2	74.7	21.7	1.5	0.7	0.5	0.4	0.2	0.3
L_1	65.0	31.1	1.7	1.0	0.4	0.3	0.2	0.3
L_2	57.7	32.5	5.5	1.6	0.6	0.6	0.8	0.7
M_1	76.4	19.2	2.4	1.1	0.3	0.2	0.2	0.2
M_2	56.6	35.7	3.8	1.7	0.6	0.4	0.6	0.6
N_1	82.7	14.8	1.0	0.6	0.3	0.2	0.2	0.2
N_2	65.0	22.2	3.7	2.9	2.3	1.6	1.3	1.1
$(H/I)_1$	81.2	15.2	2.1	0.8	0.3	0.2	0.2	0.2
$(H/I)_2$	42.1	38.4	8.8	4.6	2.5	1.0	1.3	1.4
NE Corner of Boston Co. Bldg.	54.0	34.9	5.1	2.0	1.5	0.9	1.1	0.5

as indicated on Fig. 3. The symbol "+" means a small probability, smaller than 0.1% but greater than zero.

Location A, on the Boston Public Garden approximately 360 feet north of Boylston Street and 100 feet east of Arlington Street. The data summary in Table 2 shows that there is a very slight increase in wind speeds over 20 mph, from 5.8% to 6.2% occurrence frequency which is not a significant change. The 10-20 mph winds would occur 10% more frequently after construction of the project. This is due to an enhancement of wind speeds from the soutwest quadrant. Since southwest winds are more dominant in summer (see Appendix A), this enhancement might be considered beneficial and will provide additional cooling effects at A in summer. The maximum acceleration factors measured here were 0.9 for ENE winds for the present-day site and 1.0 in SSW winds with the new project.

The fact that the velocity changes encountered at this location were relatively small serves as an indication of the range of influence of the proposed project on conditions on the Garden and Common.

Location B, on the Boston Public Garden approximately 50 feet north of Boylston Street and 80 feet east of Arlington Street. Conditions here were affected by the project more than at A. As will be discussed later, the effects are due primarily to the tower building at the intersection of Arlington and Boylston Streets. Table 2 shows an increase in frequency of winds over 20 mph from 2% to 11%, i.e., about 3 days per month. The breakdown of these speeds in Table 3 shows that 7% of this 9% increase occurs with wind speeds under 30 mph, and comparison of the B_2 data with conditions at the Boston Company building show about 50% less frequency for wind speeds over 30 mph at location B.

The occurrence frequency for wind speeds in the 10-20 mph range increases from 16% to 35% as a result of the new project. Most of the increase is due to winds from the southwest quadrant which may have beneficial results in summer in contrast to the negative effects of the increased wind speeds such as wind chill effects in winter.

The largest acceleration factors measured were 0.7 in N winds for the present-day site, and 1.3 in SSW winds with the new project.

Location C, approximately 80 feet in from Boylston Street and 400 feet east of Arlington Street. Conditions here will be very little changed from present day by the new project. Wind speeds over 20 mph occur on about 1 day a month (3%) for both configurations tested, and 10-20 mph wind speeds will increase in frequency from 20% to 27% or from about 6 to 8 days per month. The largest acceleration factors measured were 0.9 in NW winds for present day, and 1.0 in E winds after the new project.

Location D, on the Boston Public Garden approximately 80 feet from Boylston and 60 feet from Charles Street. Conditions here are mildly improved by the erection of the new project. Wind speeds over 20 mph occur approximately 4% of the time instead of 7% for present day. Wind speeds in the 10-20 mph range will occur 24% of the time with the new project instead of 31% for the present-day site. The changes result mainly from the slowing down of the northerly winds approaching the new project from over the Common and Garden. The largest acceleration factors measured were 1.0 for present day in WNW winds, and 1.2 in E winds with the new development.

Location E, on the Boston Common approximately 200 feet north of Boylston and 140 feet east of Charles Street. A small change from 4% to 7% occurs in the frequency of wind speeds over 20 mph when the new project is included. For wind speeds between 10-20 mph the frequency is increased from 26% to 35%, mainly due to easterly winds being channeled by the Boylston Street front of the new project. The largest acceleration factors measured were 1.0 in WNW winds for present day, and 1.1 in ESE winds after the new development.

Location F, on the Boylston Street sidewalk, approximately 350 feet east of Charles Street. The new project will cause an increase of 3%, or 1 day per month, in the occurrence frequency of wind speeds over 20 mph, with 10-20 mph winds on about 8 days per month compared to 6 days at present. As was the case for location E, the changes occur primarily with easterly winds. The largest acceleration factors measured

here were 0.9 in NNE winds for present day, and 1.4 in ESE winds after the new development.

Location G, on Boylston Street sidewalk approximately 400 feet east of Arlington Street. The occurrence frequency of wind speeds over 20 mph will increase from 2% to 7% as a result of the new project. Of this 5% increase, 3% is for wind speeds in the 20-30 mph range, and is due primarily to westerly winds redirected by the project frontage along Boylston Street. The largest acceleration factors measured here were 0.8 in NW winds for present day, and 1.2 in WNW winds after the new development.

Location H, on Boylston Street sidewalk approximately 10 feet from the northwest corner of the Arlington/Boylston Streets tower building. The annually averaged frequencies in Table 2 show wind speeds at H over 20 mph on approximately 9% of the time, compared to 3.6% at this location for the present-day site. The 10-20 mph wind speeds increase in frequency from 13% for present day to 29% with the new project. The largest acceleration factors measured were 0.9 in NE winds for present day and 1.5 for NNE and NE winds after the project.

Dangerous wind conditions at this location can be compared against those at two other present-day city locations, namely, the northeast corner of the Boston Company building in Government Center, and location K on Stuart Street as identified for this present study. Wind speeds over 35 mph will occur at H near the new project about 1/3 less frequently than at either K or the Boston Company building. However wind speeds over 35 mph can still occur at H on about 6 days per year.

A further significant factor is that the highest wind speeds encountered at H occur in northeast quadrant winds, while the highest wind speeds at I, around the corner on Arlington Street, will include southwesterly winds. Thus a pedestrian en route along the Arlington Street sidewalk around the corner to Boylston Street sidewalk will be subjected to high wind speeds on Boylston Street on days with northeasterly winds, and will encounter similarly high wind speeds on

Arlington Street for southwesterly winds. The number of days per month on which wind problems will be encountered by pedestrians following this route will thus be larger than the specific frequencies indicated for either H or I separately. This is indicated on Tables 2 and 3 by the data row H/I where for each wind direction the velocity used in the data processing was the larger of the two measurements made at H and I locations.

This H/I data shows that pedestrians rounding the Arlington/Boylston Street corner adjacent to the proposed tower building will encounter unpleasant or dangerous wind conditions on a very large percent of the time, close to 60% or about 20 days per month on average. This contrasts to a total frequency of 19% or about 6 days a month for wind speeds over 10 mph at this corner for the present-day site. The data indicates that this particular corner would in fact be one of the windiest street locations which has been tested in Boston to date. Remedial measures should be found to protect pedestrians in this area.

Location I, on Arlington Street sidewalk approximately 10 feet from tne northwest corner of the Arlington/Boylston Street tower building. Conditions at location I were equalled only by J in being the most severe of these tested. They will be somewhat worse than conditions at the present-day Boston Company building, since I_2 shows 13% occurrence frequency for wind speeds over 20 mph compared to 11% at the Boston Company building. As discussed under H above, pedestrians walking from I to H will additionally encounter wind problems at H on days when I is calm, and vice versa.

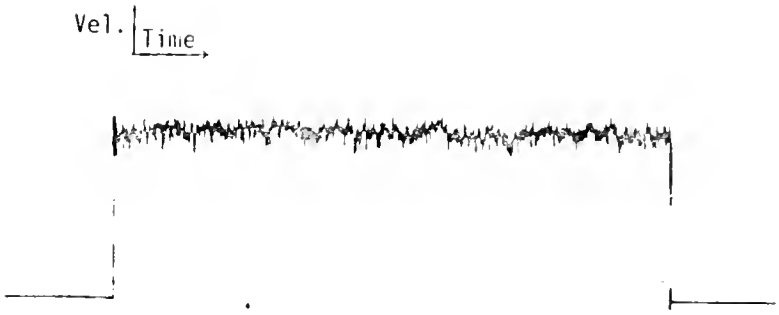
Highest wind speeds at I will occur in NNW winds, though the high occurrence frequency of winds at this location is due primarily to southwest quadrant winds, deflected downward by the tower building nearby. This is discussed further in Section 4.4. The largest acceleration factors measured at I were 0.7 in WNW winds for present day and 1.7 in NNW winds with the new project.

In addition to the high average wind speeds encountered at locations in this area, pedestrian problems are further aggravated by

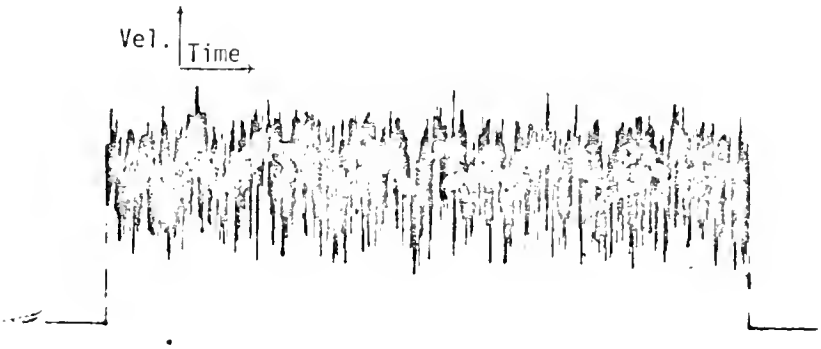
the high turbulence or gustiness of these winds. This is illustrated in Fig. 4. We define the average turbulence level as σ/V where V is the mean velocity measured, and σ is the standard deviation. In Fig. 4(a) we see the anemometer's velocity output at the reference height of 500 feet above ground. σ/V here is 3%. Figure 4(b) shows the anemometer output from location I_2 in a NNW wind. Here σ/V is 13% and we see that occasional gusts do reach to factors of 1½ to 2 times the mean value. Figure 4(c) shows the anemometer output from the same location and same wind direction but with the 480-foot tower removed. Note in this latter case (1) the reduction in mean velocity, and (2) the reduction in turbulence which, although 12% of the mean velocity, is more than halved in amplitude.

Location J, on Arlington Street west sidewalk approximately 100 feet from Boylston Street. The average occurrence frequency of faster wind speeds here is very similar to the data for location I, though for a different reason. As for I, conditions at J are somewhat worse than present day at the Boston Company building with 13% occurrence frequency for winds over 20 mph compared to 11% at the Boston Company building. The highest acceleration factors measured at J were 1.0 in a WNW wind for present day and 2.0 in NNE winds after the new development. In general, northeast and northwest quadrant winds contribute mainly to the high level of wind activity at J. Table 4 in Section 4.4 illustrates the dependence of the fastest wind speeds at J on the height of the nearby tower building. Since problems at I occur most frequently with southwesterly winds, it appears that on many of the days when pedestrians are troubled on the sidewalk near J, they will encounter sheltered conditions on the opposite sidewalk near location I, and vice versa. More specifically, with northeast quadrant winds, accelerated wind speeds will be encountered at J when much calmer conditions will prevail at I. Conversely, when southwest winds are accelerated at location I, conditions will be considerably more calm on the sidewalk near J.

Location K, on Stuart Street sidewalk approximately 520 feet east of Arlington Street. Present-day conditions at this location were



(a)



(b)

(c)

FIGURE 4. Comparative turbulence levels at location I in a NNW wind. (All traces to same scales.)

(a) turbulence level at reference height of 500 feet.

(b) turbulence level at location I_2, with 450-foot tower.

(c) turbulence level at location I_2, with tower removed.

found to be quite severe, with 29% frequency for 10-20 mph winds and 10.7% frequency for wind speeds over 20 mph. These conditions occur mainly because of channeling of northeast and southwest quadrant winds along Stuart Street, an effect that is partially negated by the increased density of the proposed project. After the project has been developed, conditions at K will be improved considerably and 10-20 mph winds will occur approximately 22% of the time, with winds over 20 mph on 3.6% of the time, or about 1 day per month. The largest acceleration factors measured were 1.4 in a N wind for present-day conditions, and 0.9 in a SSW wind with the new development.

Location L, on Stuart Street where the Charles Street underpass will be located on the new development. There is an increase in the frequency of faster wind speeds at this location after erection of the new project. Winds over 20 mph will occur approximately 10% of the time compared to 4% for present day, while 10-20 mph winds will occur with about the same frequency (32%). The increase in the faster wind speeds is due mainly to the flow through the underpass for N and NNE winds plus an additional increment for SSW winds blowing along Stuart Street. An ESE wind will produce high wind speeds at L due to the presence of the tower buildings at the east side of the project. However this wind direction is quite infrequent and contributes little to the total frequencies involved. The largest acceleration factors measured were 0.9 in SW winds for present-day conditions and 1.4 for N and ESE winds with the new development. Additional tests were run in a N wind to examine the effect of the tower building proposed to be located closely northwest of L. The acceleration factor of 1.4 at L for a N wind is reduced to 1.1 when this building is removed.

Location M, on Stuart Street sidewalk immediately south of the twin towers in the new project. A general increase in wind speeds is produced here by the new project with 10-20 mph winds on 38% of the time compared to 19% for the present-day site, and winds over 20 mph on 7.7% compared to 4.4% of the time at present. The increased frequency of the

faster wind speeds occurs for northeast quadrant winds which are enhanced by the twin tower buildings on the new project. The largest acceleration factors measured here were 1.0 in NW winds for the present-day site and 1.5 in NNE winds with the new development.

Location N, on the Providence Street sidewalk approximately 10 feet from the southwest corner of the Arlington/Boylston Street tower. Wind speeds here are considerably increased due to the presence of the adjacent tower building. Wind speeds over 20 mph will occur 12.8% of the time after the tower is built, compared to 2.5% for present-day conditions. Similarly, the occurrence frequency of 10-20 mph winds will increase from 15% to 23% as a consequence of the tower's presence. The increase in wind speed occurs mainly in easterly and westerly winds, channeled into Providence Street by the south face of the Arlington/Boylston Street tower. The largest acceleration factors measured at N were 0.9 in SSW winds for the present-day site, and 2.1 in W winds with the new development. The effect of the specific height of the Arlington/Boylston Street tower on these maximum speeds is illustrated in Table 4 of this report.

Additional tests were made for ENE and W winds on the effect of the proposed Statler Office tower. The maximum wind speed at location N in a W wind is unaffected by the Statler tower. In an ENE wind, the acceleration factor at N is reduced from 1.6 to 1.1 by eliminating the proposed Statler tower building. It is perhaps fair to say conditions at N are affected by the interaction of the Statler and the Arlington/Boylston Street towers with the natural winds. However the scope of the present-study did not include a detailed investigation of the relative effects of the Statler tower and the Arlington/Boylston Street towers as independent parameters.

4.3 Effect of the Height of the Arlington/Boylston Street Tower

The most severe wind conditions at the project were encountered close to the Arlington/Boylston Street tower buildings. This is due to the effect which was illustrated in Fig. 1. For the development modeled in this study, westerly winds striking the tower building are deflected downward onto Arlington and Boylston Streets. The escape paths around the northwest and southwest corners of the building contribute to the wind conditions at locations H and N. This is illustrated in Fig. 5 where the bubble visualization technique shows the flow pattern around the northwest corner of the building in a westerly wind. The paths of the neutrally buoyant bubbles appear as white streaks in the photograph. Note how the wind is flowing downward from higher elevations toward ground level. In the case illustrated the accelerated winds are flowing toward location H and along Boylston Street.

Additional tests were carried out to examine the sensitivity of wind speeds in the area to the height of the tower. At each of locations N, I, J, and B, measurements were made for the wind direction which had produced the largest acceleration factor in the primary test program. With the tower model now segmented, acceleration factors were measured for the original tower height (450 feet) and for successive 100-foot reductions in height. The results are shown in Table 4.

Care must be exercised in assessing the data in Table 4. It does illustrate that ground level wind speeds are dependent on the building height. However, for different wind directions the "effective height" of the tower, i.e., its height relative to the average height of the buildings upwind, will be different and so the impact on ground level winds will vary. As a generalization, Table 4 shows that the taller the tower, the faster will be the ground level winds. However, a full analysis of the effect of a reduction in the tower height will require testing around the 16 compass points used in the primary study reported here.

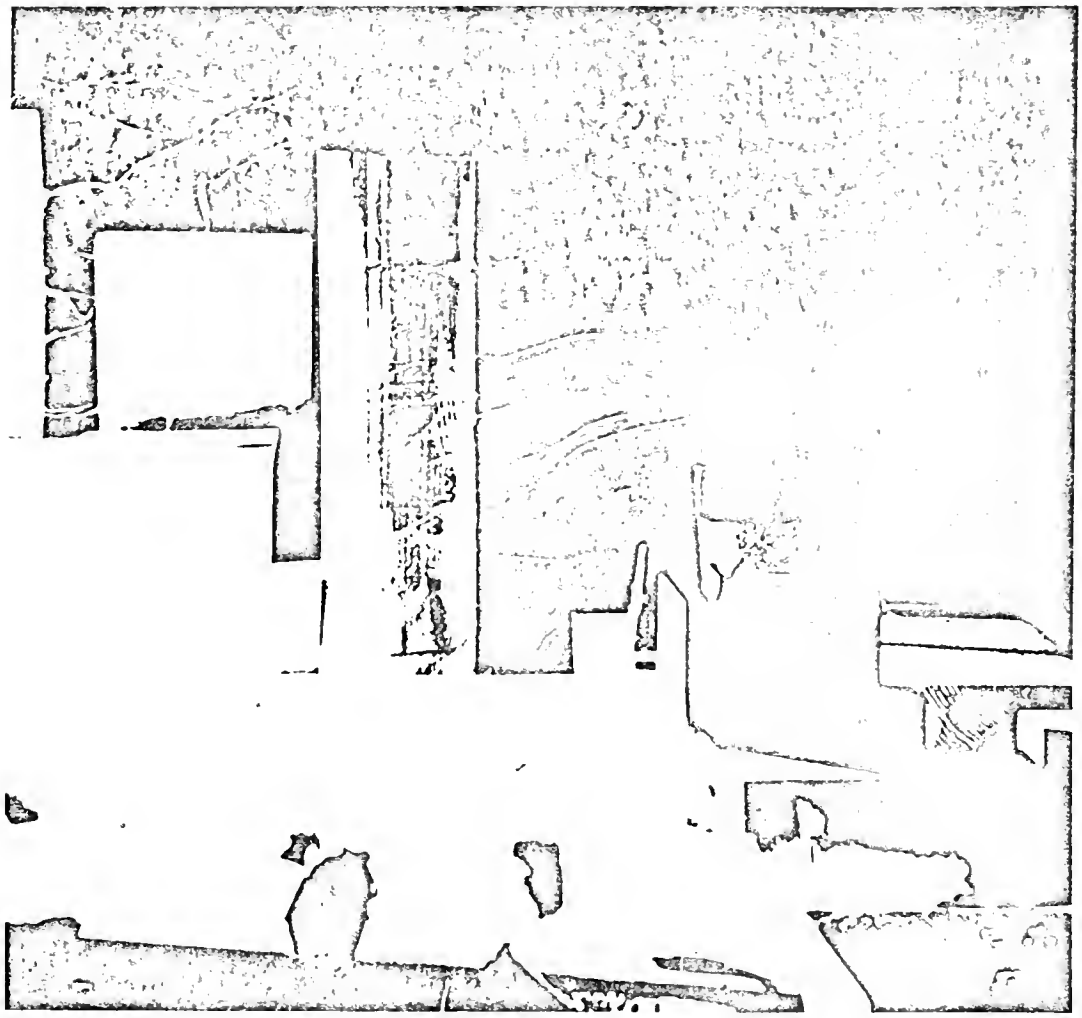


FIGURE 5. Flow around the northwest corner of the Arlington/Boylston Street tower in a west wind. Flow is from right to left. Note the path of the bubbles showing the wind flowing down towards street level, past location H for the configuration illustrated here.

TABLE 4

ACCELERATION FACTORS, V/V_{33}, MEASURED AT LOCATIONS N, I, J, AND B FOR VARIOUS HEIGHTS OF THE ARLINGTON/BOYLSTON STREET TOWER

Location	Wind	Tower Height			
		450'	350'	250'	150'
		Acceleration factor, V/V_{33}			
N	N	2.1	1.8	0.8	0.2
I	NNW	1.7	1.6	1.2	0.7
J	NNE	2.0	2.0	1.9	1.2
B	SSW	1.3	1.2	0.9	0.8

4.4 Summary of Results

The data generated in this wind tunnel study provide information on levels of wind activity at specific locations, in addition to indicating the approximate range on the Public Garden within which wind conditions will be affected by the proposed development. At locations A, C, D, and E on the Boston Public Garden and Common, the changes in average wind conditions are relatively small. At A, C, and E there is a general increase in wind speeds, while at D there is an overall reduction in wind speeds. The most severe changes in wind speeds on the Garden occur near location B. Here the effects of the Arlington/Boylston Street tower are clearly evident in the enhancement of ground level wind speeds. Table 4 illustrates the dependence of the fastest wind speeds at this location on the height of the adjacent tower building.

Wind speeds on the Boylston Street sidewalk at locations F and G are increased as a result of the new development. In general terms, the occurrence frequencies of all wind speeds over 10 mph are increased from 22% to 31% at F, and from 17% to 31% at G by the new development. This is at best undesirable, and will detract from the potential of these locations for window shopping and general pedestrian traffic. Since the primary concern at these locations is for the pedestrian environment on the sidewalk, it is suggested that final designs should include protective facilities such as canopies or enclosed or recessed walkways.

The locations found to incur the worst wind conditions near the new development are clearly those adjacent to the 450-foot tower at the intersection of Arlington and Boylston Streets. At test locations H, I, J, and N substantial increases were measured in the occurrence frequency of faster wind speeds. Acceleration factors between 1.5 and 2.1 were measured at those locations. Thus 30 mph wind speeds at Logan could produce ground level wind speeds at these locations between 45 and 63 mph. These are definitely hazardous to pedestrians and the liklihood exists that people could be blown over by such wind speeds. Conditions at these

locations are severe because of the complete exposure of a tall building to the prevailing westerly winds. Additional tests were carried out for locations N, I, J, and B to examine the effects of the tower height on the fastest wind speeds measured at these locations. The results are presented in Table 4. They show how the wind accelerations are reduced as the height of the tower is reduced. If the tower height is fixed at 450 feet, then detailed testing will be required to examine the details of street level design needed to protect pedestrians from frequently unpleasant and dangerous winds.

On Stuart Street sidewalk wind levels at K were improved by the new development, but at L and M wind conditions will be somewhat less attractive than on the Boylston Street sidewalk at F and G. Consideration should be given to pedestrian protection in the form of canopies or enclosed arcades to enhance Stuart Street as an attractive pedestrian area.

5. CONCLUSIONS

At four locations tested on the Garden and Common (A, C, D, and E on Fig. 3) the changes in wind conditions resulting from the new development are relatively mild. At three of these four locations (A,C, and E) average wind speeds are increased; at the fourth location (D), average wind speeds are decreased. The largest changes in wind activity on the Garden occur at the southwest corner, near location B on Fig. 3. This is the result of the 450-foot tower building proposed at the corner of Arlington and Boylston Streets.

Conditions on the sidewalks both at the base of the building and across the street (locations H, I, J, and N) are undesirably windy and will quite frequently be dangerous with the liklihood of people being blown over. It is recommended that final designs for this part of the project must provide protective facilities for pedestrians if the tower is built to the proposed height of 450 feet. Table 4 of this report illustrates that the problems will be less severe if the tower height is reduced.

On the Boylston and Stuart Street sidewalks it is recommended that protective canopies or arcades be considered to provide shelter for pedestrians, since ambient wind activity will otherwise be unpleasantly high.

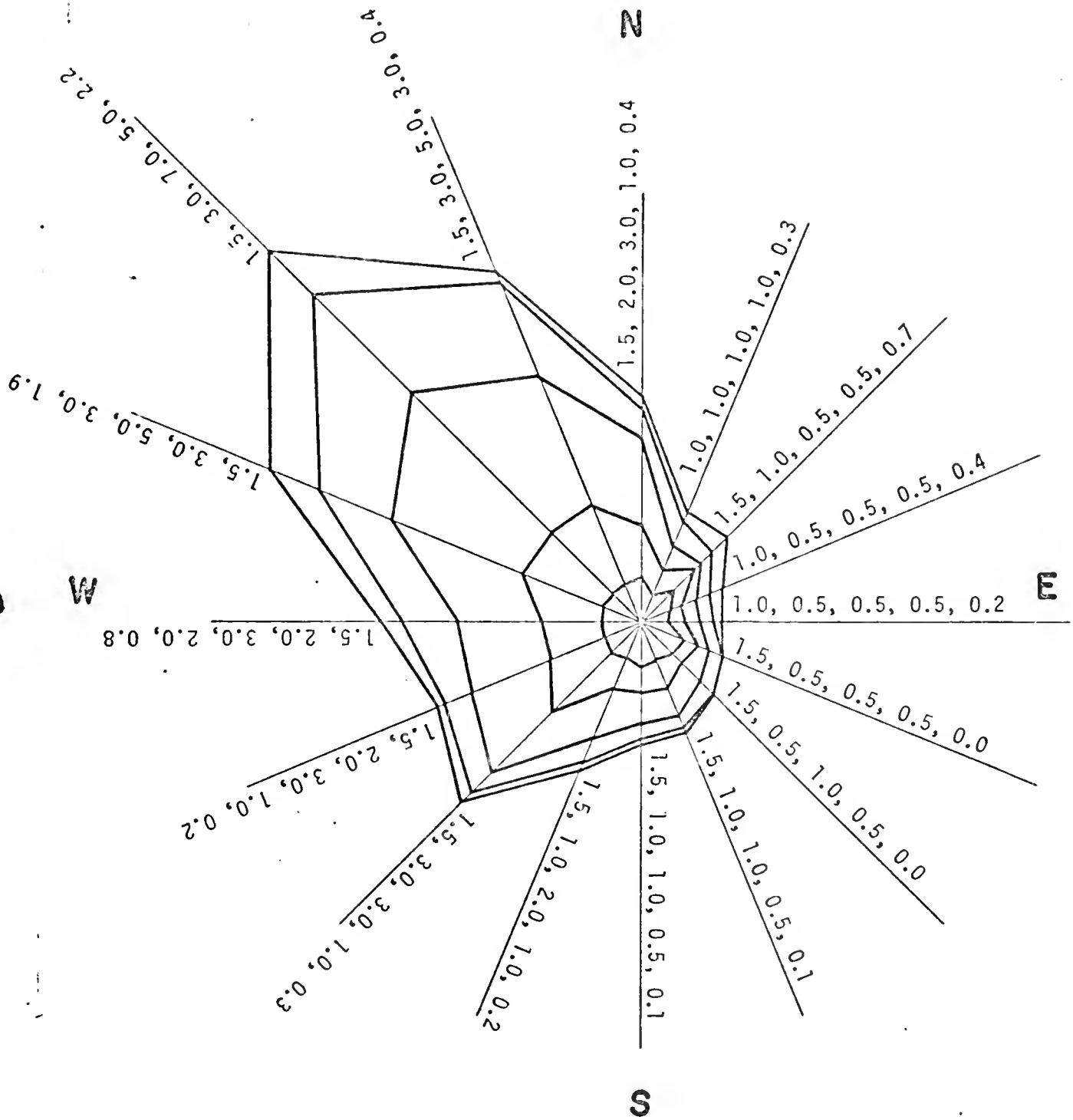
APPENDIX A

WINDROSES FOR BOSTON, MASSACHUSETTS

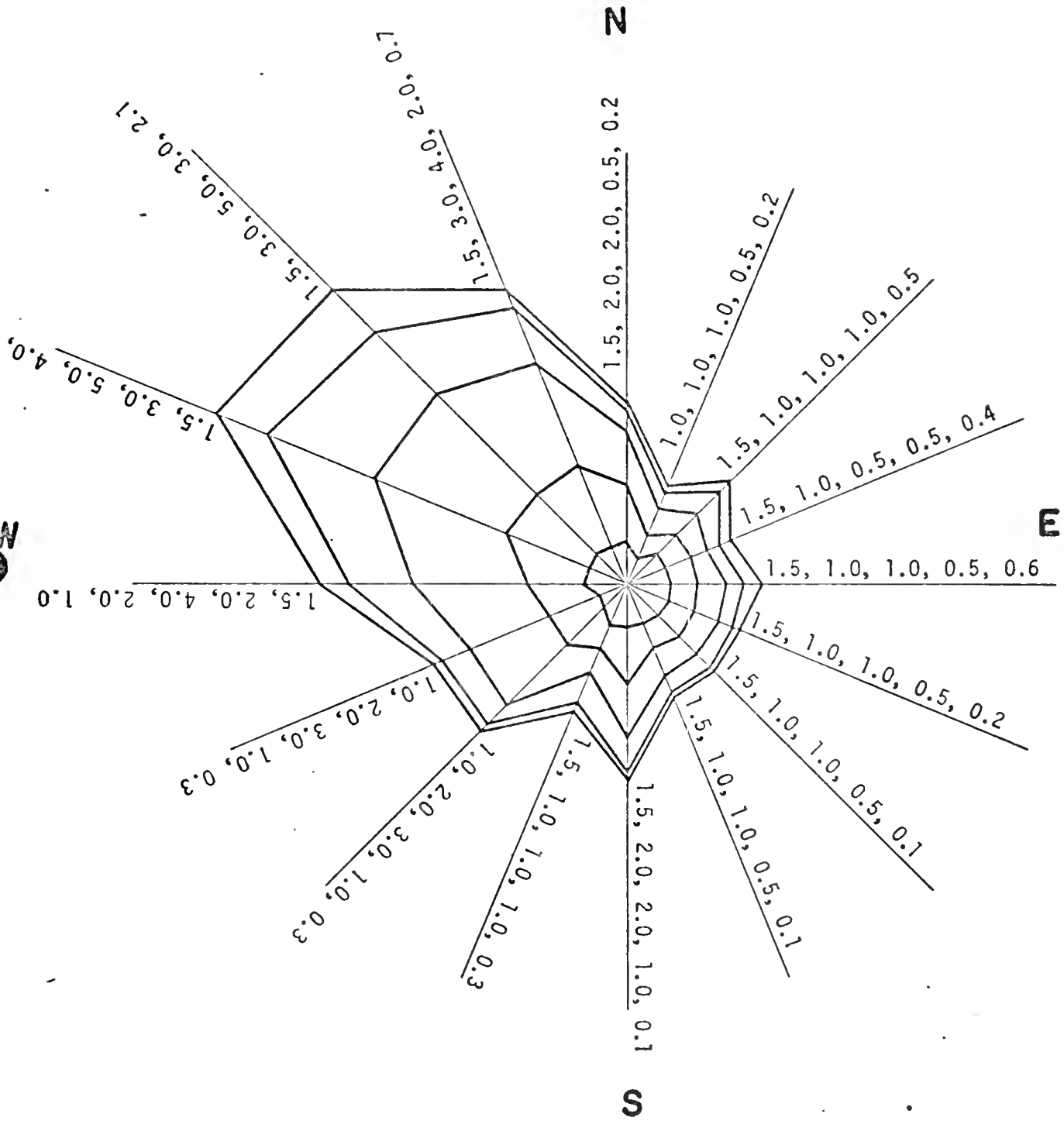
KEY:

Directions are those from which the wind blows. The top vertical line represents North winds. Clockwise follow NNE, NE, ENE, etc. The innermost circle represents the percent occurrence of (0-7) mph winds. The first number expresses the numerical value of this occurrence to the nearest whole percent. Then, radiating outwards for each of sixteen compass points appear percentages for occurrence of winds in 8-12, 13-18, 19-24, 25+ mph speed ranges. The sequence of numbers associated with a particular wind direction indicates the percent frequency of wind speeds in these ranges, 0-7, 8-12, 13-18, 19-24 and over 25 mph.

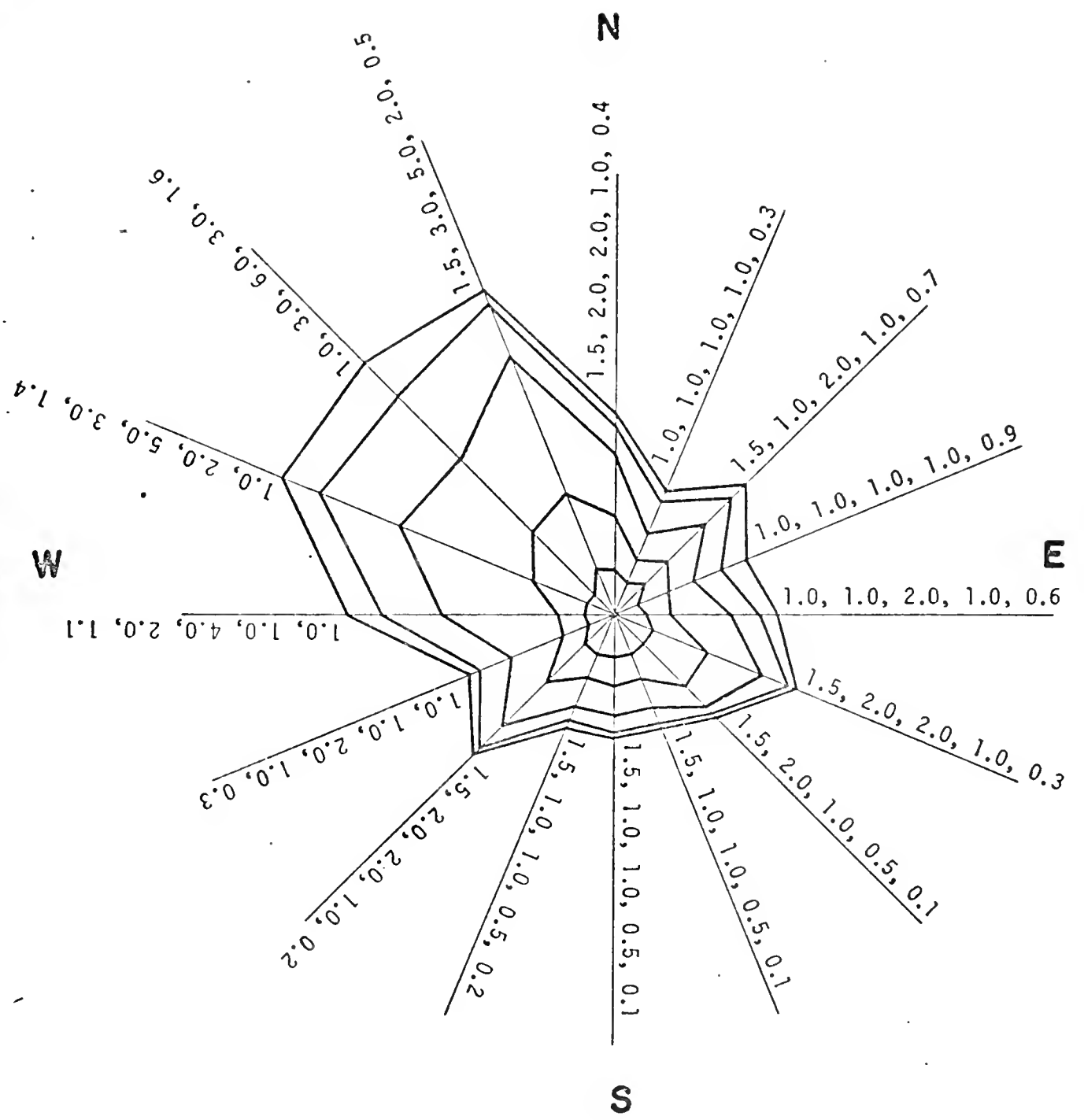
Data is presented for average occurrences for each month and for an annual average. The data base is the National Weather Bureau of Hourly Observations for Boston, Massachusetts, for the ten-year interval 1951-1960.


N
1.5, 2.0, 3.0, 1.0, 0.4
1.0, 1.0, 1.0, 1.0, 0.3
1.5, 1.0, 0.5, 0.5, 0.7
1.0, 0.5, 0.5, 0.5, 0.4
E
1.0, 0.5, 0.5, 0.5, 0.2
1.5, 0.5, 0.5, 0.5, 0.0
1.5, 0.5, 1.0, 0.5, 0.0
1.5, 1.0, 1.0, 0.5, 0.1
1.5, 1.0, 1.0, 0.5, 0.1
1.5, 1.0, 2.0, 1.0, 0.2
1.5, 3.0, 3.0, 1.0, 0.3
1.5, 2.0, 3.0, 1.0, 0.2
W
1.5, 2.0, 3.0, 2.0, 0.8
1.5, 3.0, 5.0, 3.0, 1.9
1.5, 3.0, 7.0, 5.0, 2.2
1.5, 3.0, 5.0, 3.0, 0.4
S

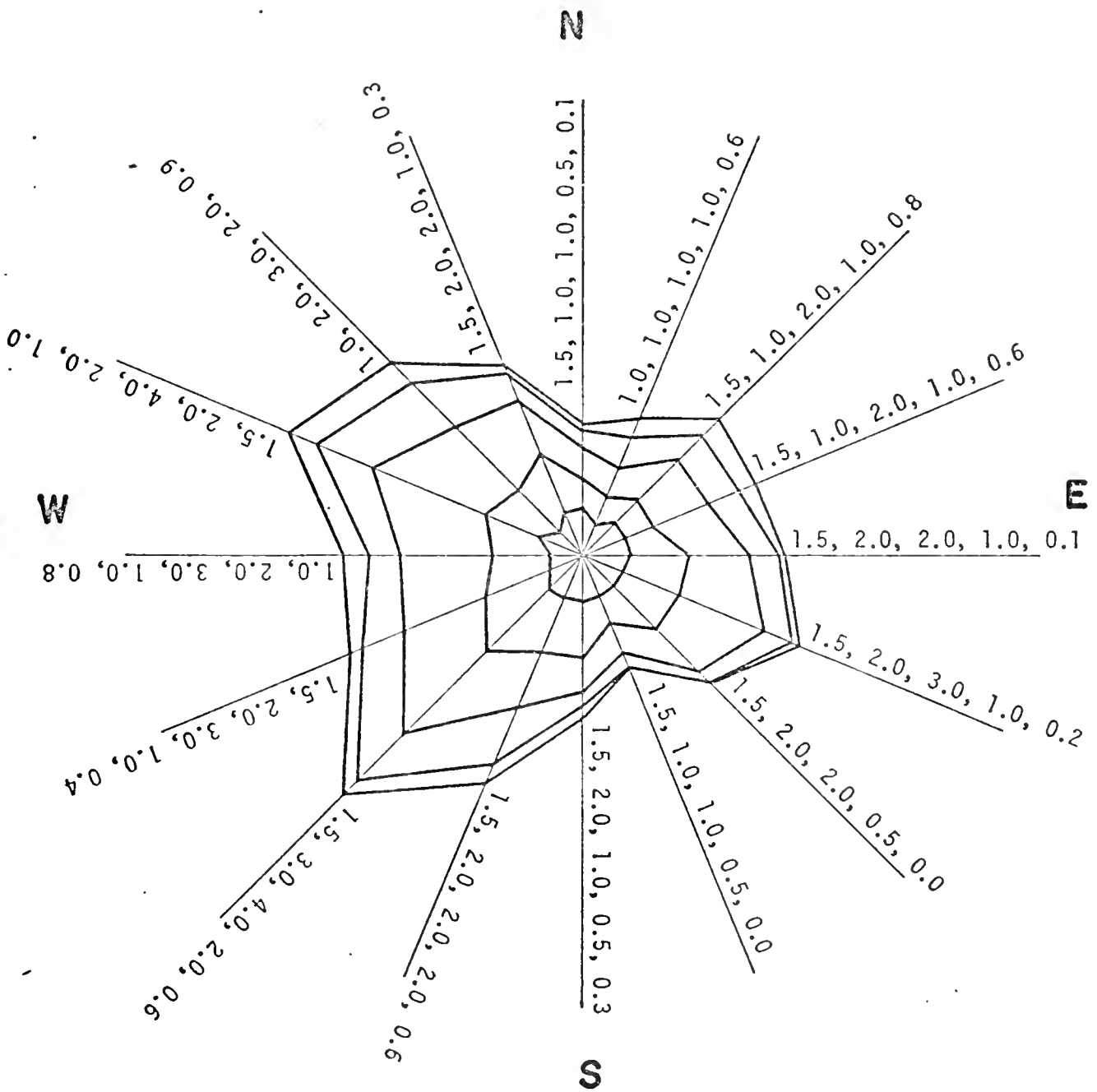
JANUARY


N
1.5, 2.0, 2.0, 0.5, 0.2
1.0, 1.0, 1.0, 0.5, 0.2
1.5, 1.0, 1.0, 1.0, 0.5
1.5, 1.0, 0.5, 0.5, 0.4
E
1.5, 1.0, 1.0, 0.5, 0.6
1.5, 1.0, 1.0, 0.5, 0.2
1.5, 1.0, 1.0, 0.5, 0.1
1.5, 1.0, 1.0, 0.5, 0.1
S
1.5, 2.0, 2.0, 1.0, 0.1
1.5, 1.0, 1.0, 1.0, 0.3
1.0, 2.0, 3.0, 1.0, 0.3
1.0, 2.0, 3.0, 1.0, 0.3
1.5, 2.0, 4.0, 2.0, 1.0
W
1.5, 3.0, 5.0, 4.0,
1.5, 3.0, 5.0, 3.0, 2.1
1.5, 3.0, 4.0, 2.0, 0.7

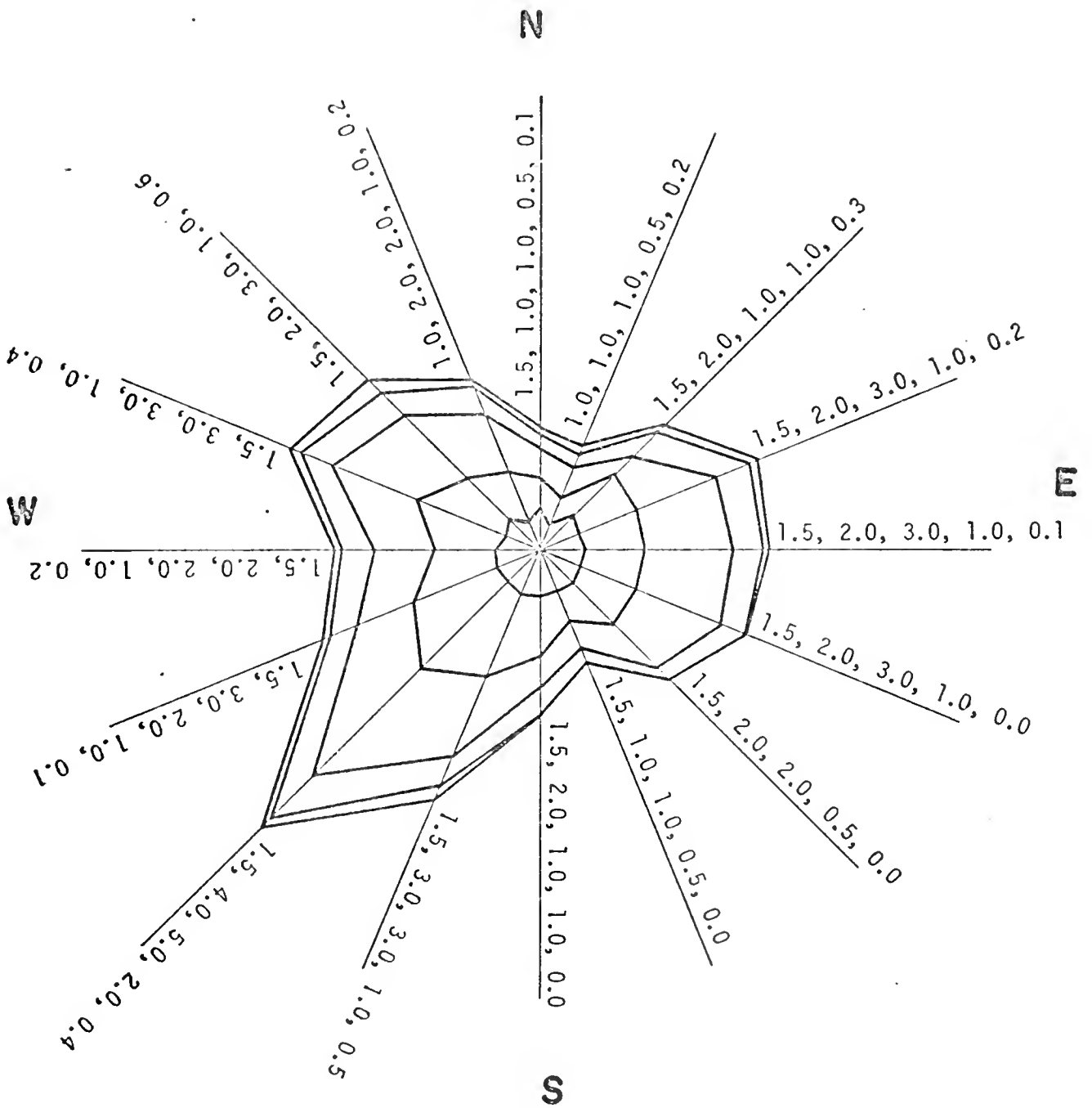
FEBRUARY


N
1.5, 2.0, 2.0, 1.0, 0.4
1.0, 1.0, 1.0, 1.0, 0.3
1.5, 1.0, 2.0, 1.0, 0.7
1.0, 1.0, 1.0, 1.0, 0.9
E
1.0, 1.0, 2.0, 1.0, 0.6
1.5, 2.0, 2.0, 1.0, 0.3
1.5, 2.0, 1.0, 0.5, 0.1
1.5, 1.0, 1.0, 0.5, 0.1
1.5, 1.0, 1.0, 0.5, 0.1
1.5, 1.0, 1.0, 0.5, 0.2
1.5, 2.0, 2.0, 1.0, 0.2
1.0, 1.0, 2.0, 1.0, 0.3
1.0, 1.0, 4.0, 2.0, 1.1
W
1.0, 2.0, 5.0, 3.0, 1.4
1.0, 3.0, 6.0, 3.0, 1.6
1.5, 3.0, 5.0, 2.0, 0.5
S

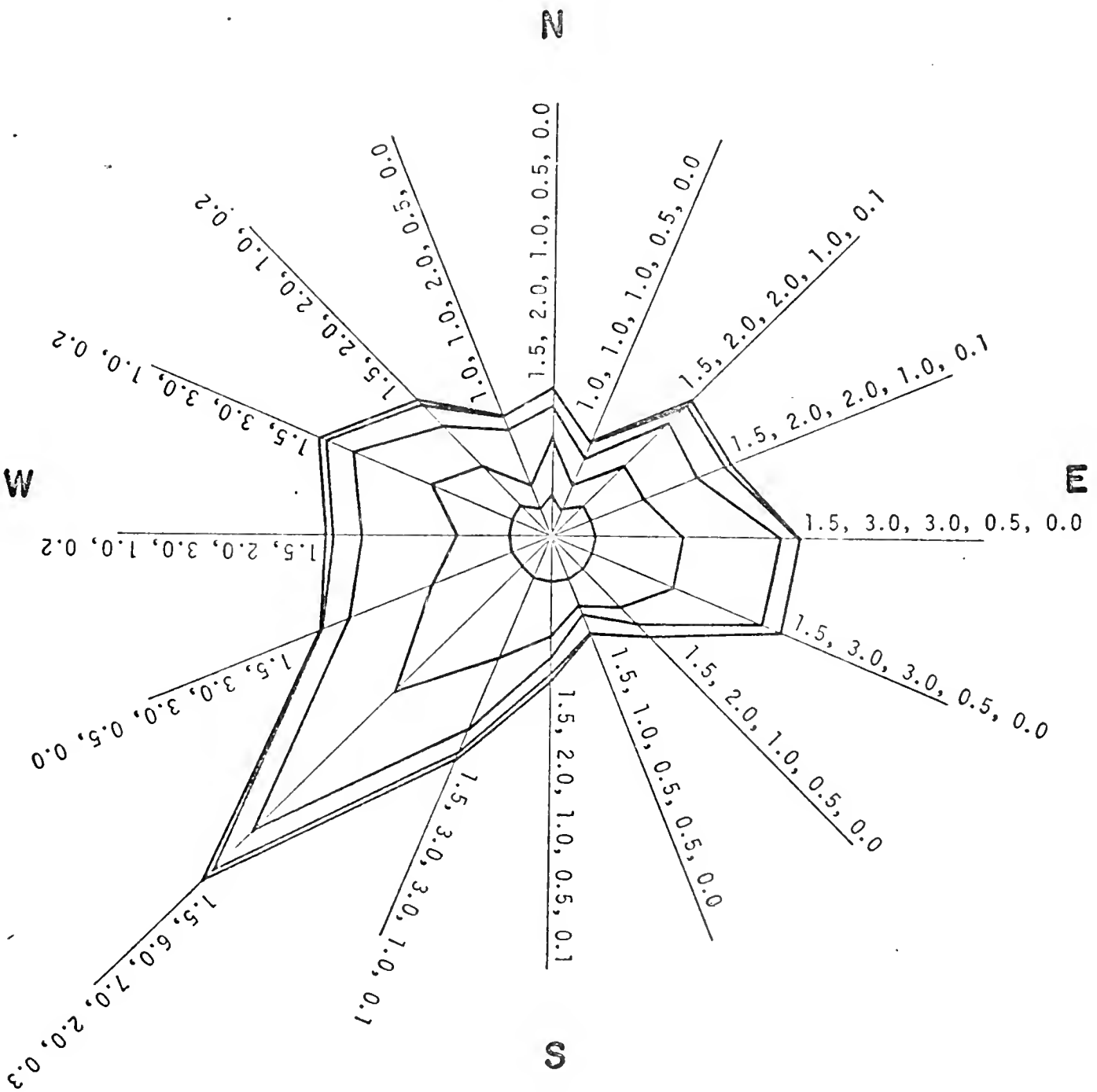
MARCH


N
1.5, 1.0, 1.0, 0.5, 0.1
1.0, 1.0, 1.0, 1.0, 0.6
1.5, 1.0, 2.0, 1.0, 0.8
1.5, 1.0, 2.0, 1.0, 0.6
E
1.5, 2.0, 2.0, 1.0, 0.1
1.5, 2.0, 3.0, 1.0, 0.2
1.5, 2.0, 2.0, 0.5, 0.0
1.5, 1.0, 1.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.3
S
1.5, 2.0, 2.0, 2.0, 0.6
1.5, 3.0, 4.0, 2.0, 0.6
1.5, 2.0, 3.0, 1.0, 0.4
W
1.0, 2.0, 3.0, 1.0, 0.8
1.5, 2.0, 4.0, 2.0, 1.0
1.0, 2.0, 3.0, 2.0, 0.9
1.5, 2.0, 2.0, 1.0, 0.3

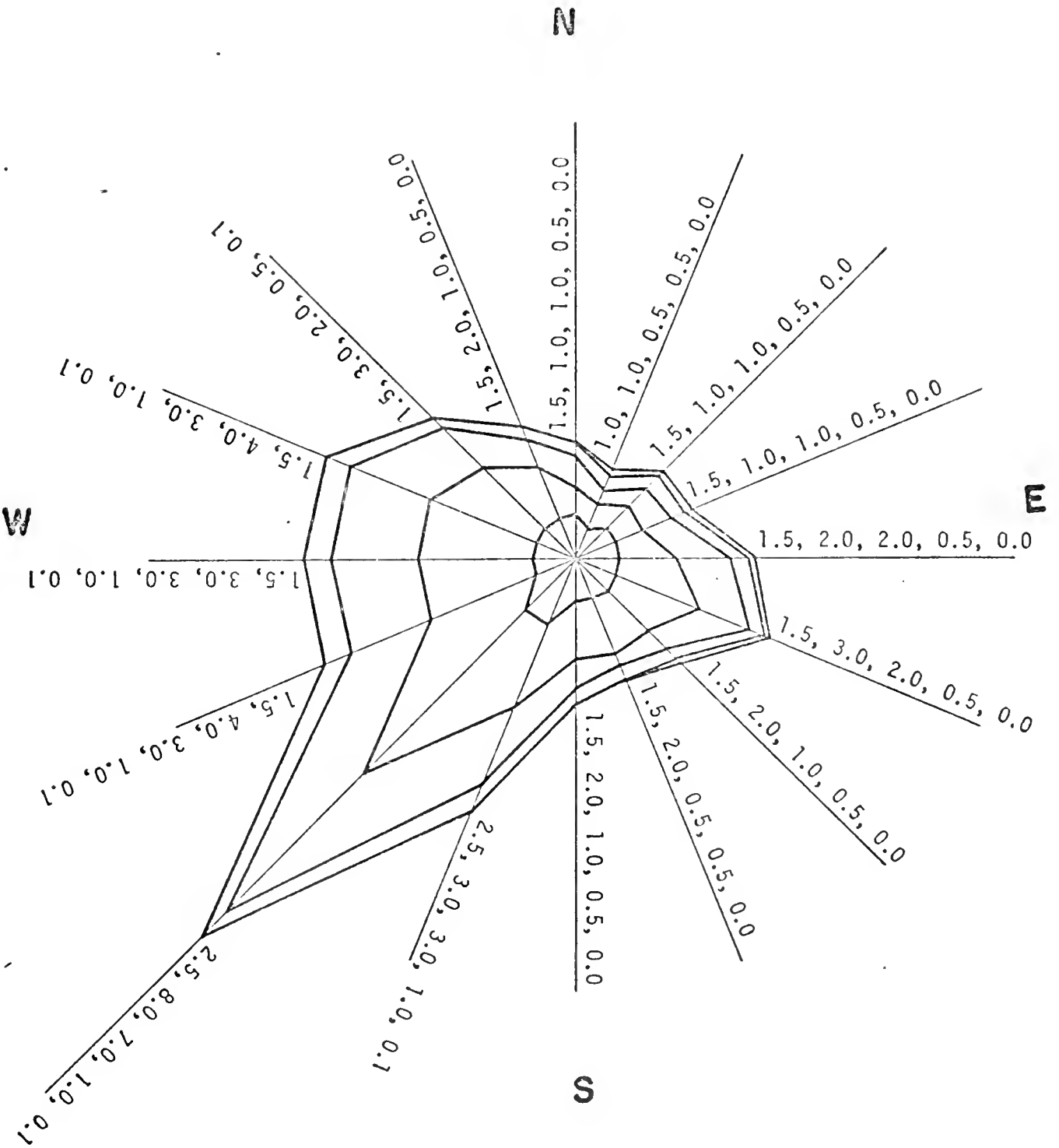
APRIL


N
E
S
W
1.5, 1.0, 1.0, 0.5, 0.1
1.0, 1.0, 1.0, 0.5, 0.2
1.5, 2.0, 1.0, 1.0, 0.3
1.5, 2.0, 3.0, 1.0, 0.2
1.5, 2.0, 3.0, 1.0, 0.1
1.5, 2.0, 3.0, 1.0, 0.0
1.5, 2.0, 2.0, 0.5, 0.0
1.5, 1.0, 1.0, 0.5, 0.0
1.5, 2.0, 1.0, 1.0, 0.0
1.5, 3.0, 3.0, 1.0, 0.5
1.5, 4.0, 5.0, 2.0, 0.4
1.5, 3.0, 2.0, 1.0, 0.1
1.5, 2.0, 2.0, 1.0, 0.2
1.5, 3.0, 3.0, 1.0, 0.4
1.5, 2.0, 3.0, 1.0, 0.6
1.0, 2.0, 2.0, 1.0, 0.2

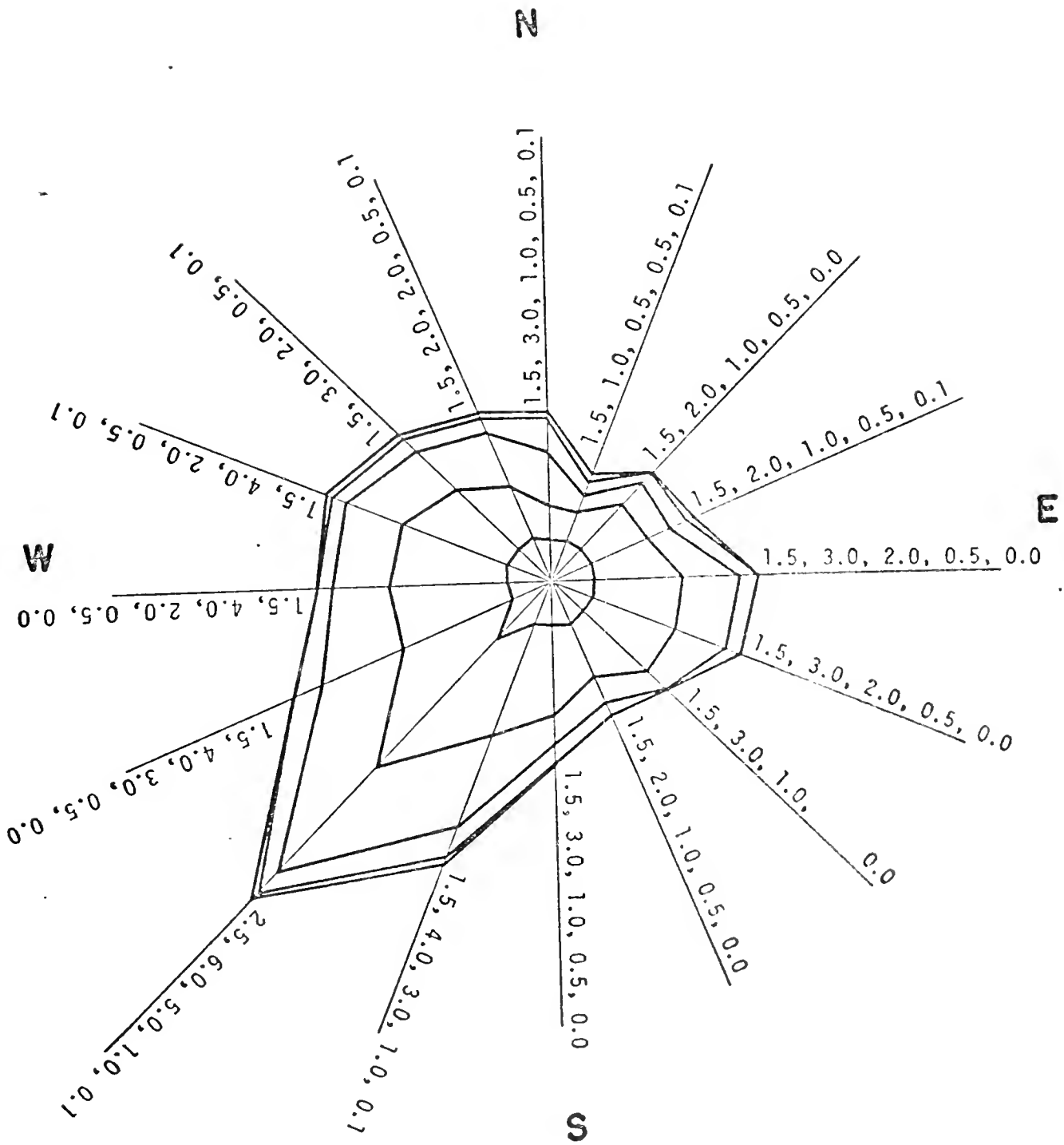
MAY

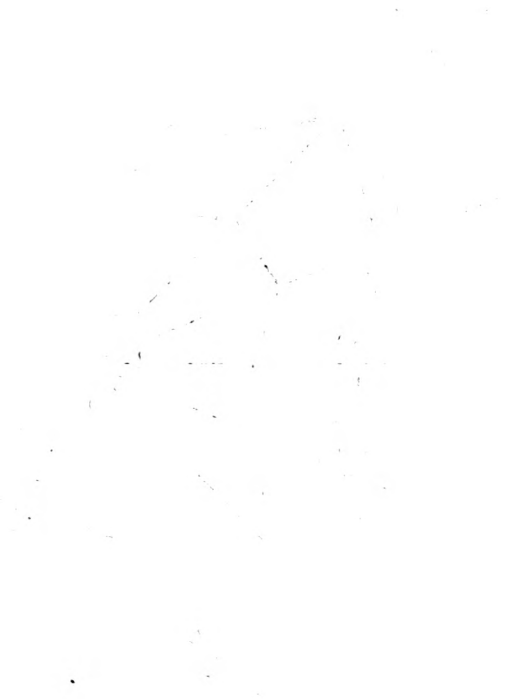

N
E
S
W
1.5, 2.0, 1.0, 0.5, 0.0
1.0, 1.0, 1.0, 0.5, 0.0
1.5, 2.0, 2.0, 1.0, 0.1
1.5, 2.0, 2.0, 1.0, 0.1
1.5, 3.0, 3.0, 0.5, 0.0
1.5, 3.0, 3.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 1.0, 0.5, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.1
1.5, 3.0, 3.0, 1.0, 0.1
1.5, 6.0, 7.0, 2.0, 0.3
1.5, 3.0, 3.0, 0.5, 0.0
1.5, 2.0, 3.0, 1.0, 0.2
1.5, 3.0, 3.0, 1.0, 0.2
1.5, 2.0, 2.0, 1.0, 0.2
1.0, 1.0, 2.0, 0.5, 0.0

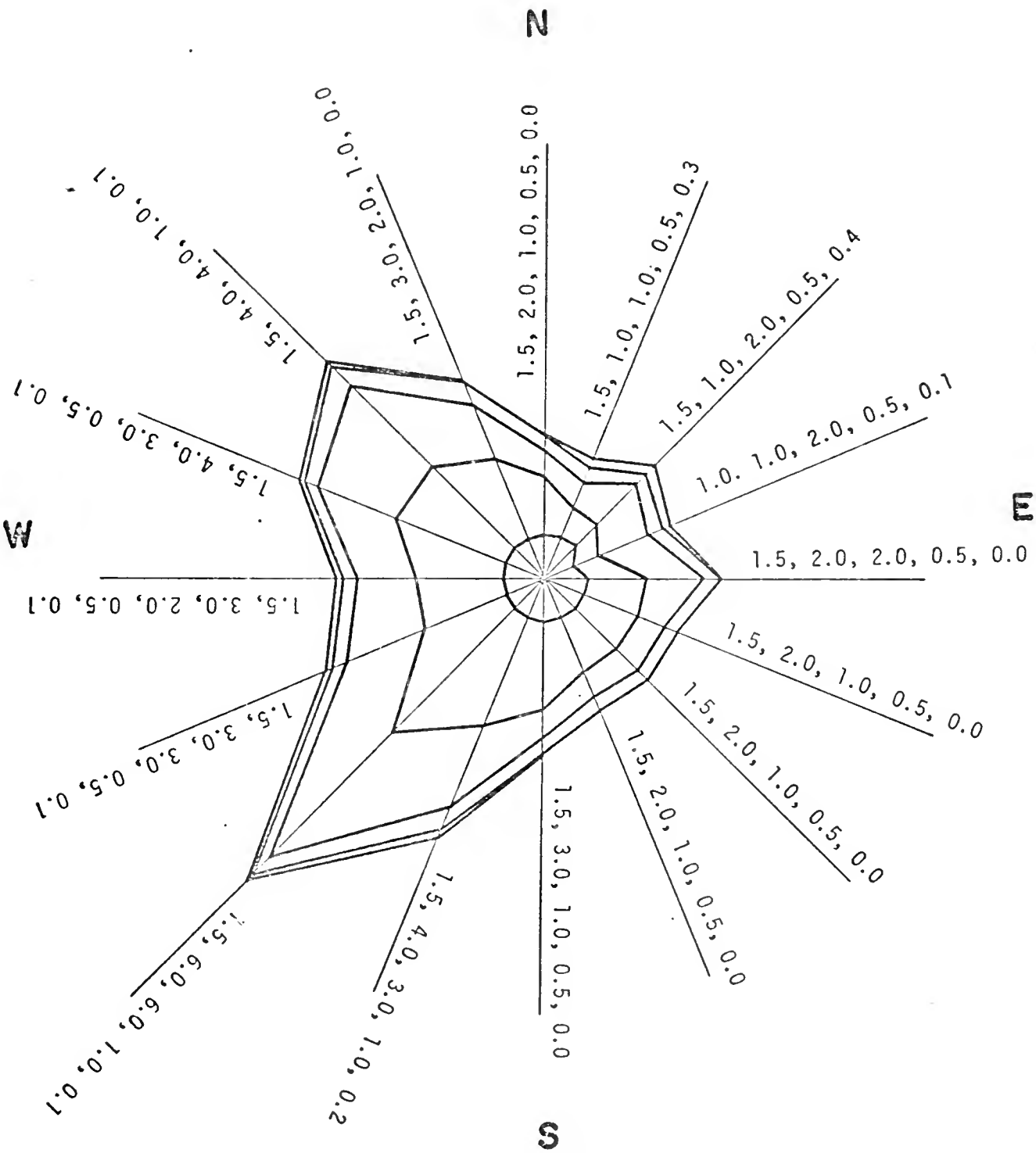
JUNE


N
E
S
W
1.5, 1.0, 1.0, 0.5, 0.0
1.0, 1.0, 0.5, 0.5, 0.0
1.5, 1.0, 1.0, 0.5, 0.0
1.5, 1.0, 1.0, 0.5, 0.0
1.5, 2.0, 2.0, 0.5, 0.0
1.5, 3.0, 2.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 2.0, 0.5, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.0
2.5, 3.0, 3.0, 1.0, 0.1
2.5, 8.0, 7.0, 1.0, 0.1
1.5, 4.0, 3.0, 1.0, 0.1
1.5, 3.0, 3.0, 1.0, 0.1
1.5, 4.0, 3.0, 1.0, 0.1
1.5, 3.0, 2.0, 0.5, 0.1
1.5, 2.0, 1.0, 0.5, 0.0

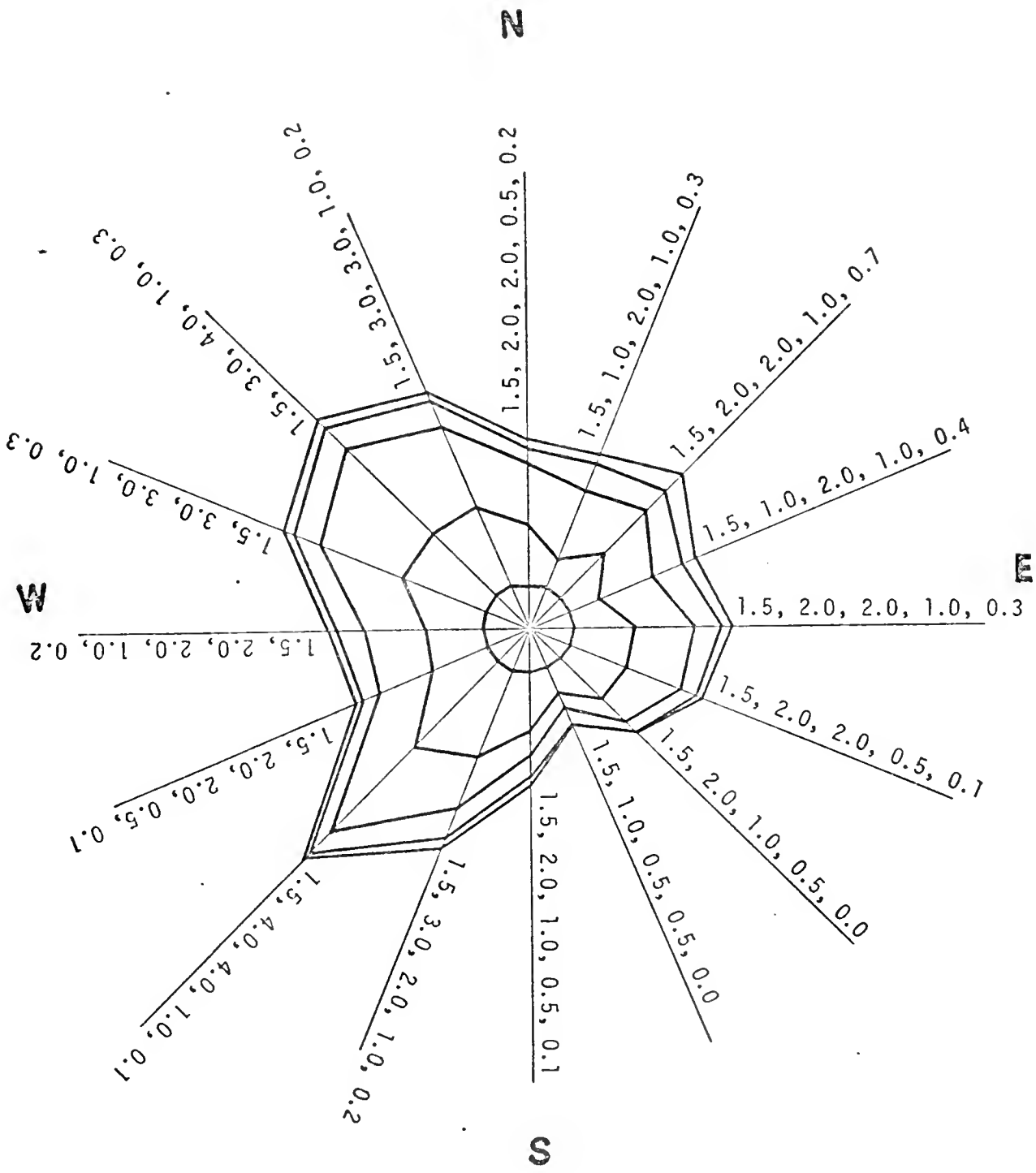
JULY


N
1.5, 3.0, 1.0, 0.5, 0.1
1.5, 2.0, 2.0, 0.5, 0.1
1.5, 3.0, 2.0, 0.5, 0.1
1.5, 4.0, 2.0, 0.5, 0.1
W
1.5, 4.0, 2.0, 0.5, 0.0
1.5, 4.0, 3.0, 0.5, 0.0
2.5, 6.0, 5.0, 1.0, 0.1
1.5, 4.0, 3.0, 1.0, 0.1
S
1.5, 3.0, 1.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 3.0, 1.0, 0.0
1.5, 3.0, 2.0, 0.5, 0.0
E
1.5, 3.0, 2.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.1
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 1.0, 0.5, 0.5, 0.1

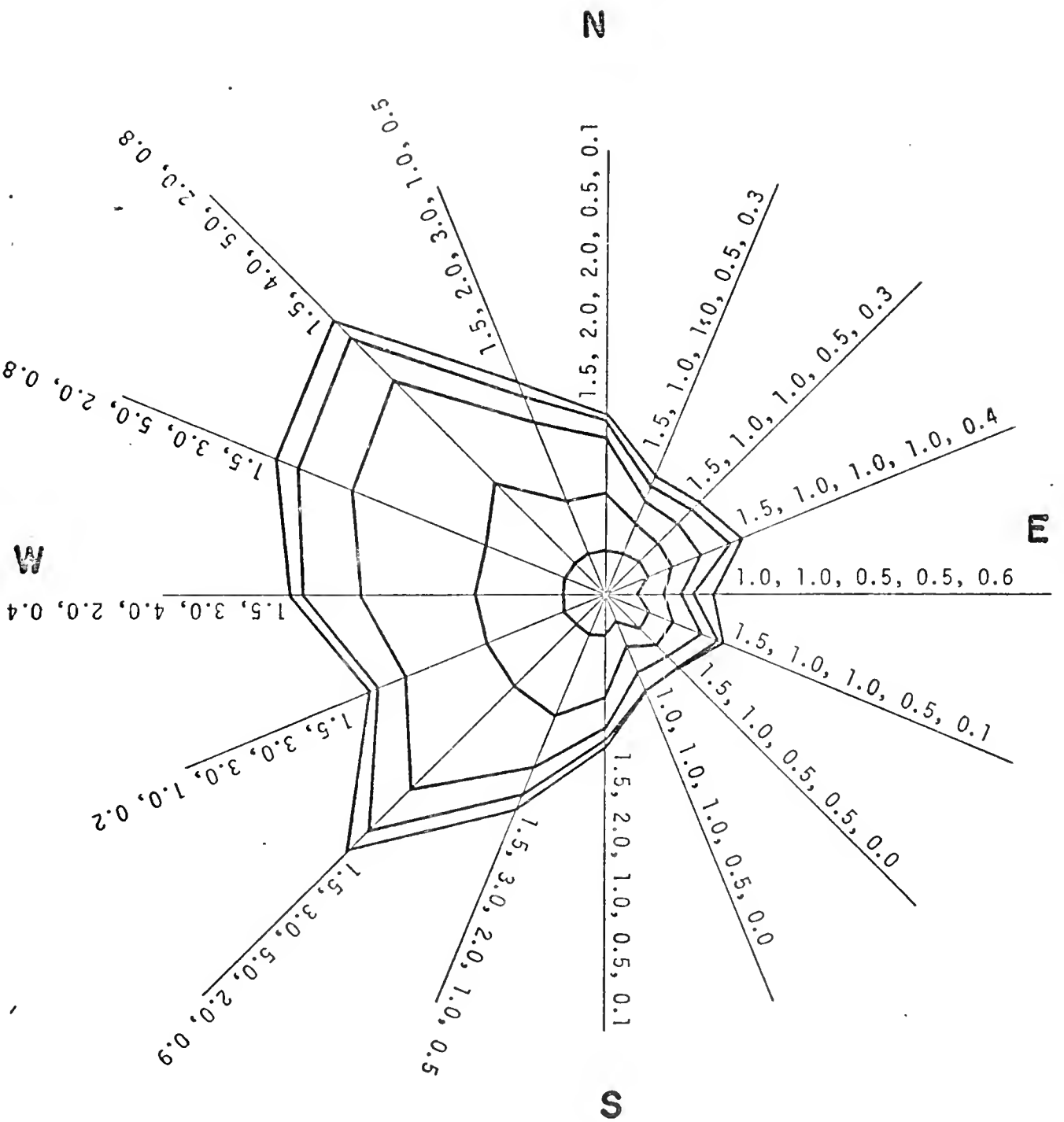



N
E
S
W
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 1.0, 1.0, 0.5, 0.3
1.5, 1.0, 2.0, 0.5, 0.4
1.0. 1.0, 2.0, 0.5, 0.1
1.5, 2.0, 2.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 3.0, 1.0, 0.5, 0.0
1.5, 4.0, 3.0, 1.0, 0.2
1.5, 6.0, 6.0, 1.0, 0.1
1.5, 3.0, 2.0, 0.5, 0.1
1.5, 3.0, 3.0, 0.5, 0.1
1.5, 4.0, 3.0, 0.5, 0.1
1.5, 4.0, 4.0, 1.0, 0.1
1.5, 3.0, 2.0, 1.0, 0.0

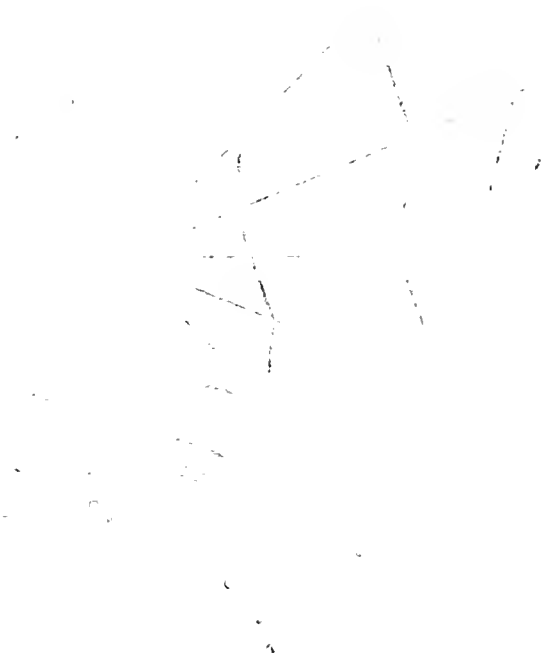
SEPTEMBER


N
1.5, 2.0, 2.0, 0.5, 0.2
1.5, 1.0, 2.0, 1.0, 0.3
1.5, 2.0, 2.0, 1.0, 0.7
1.5, 1.0, 2.0, 1.0, 0.4
E
1.5, 2.0, 2.0, 1.0, 0.3
1.5, 2.0, 2.0, 0.5, 0.1
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 1.0, 0.5, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.1
1.5, 3.0, 2.0, 1.0, 0.2
1.5, 4.0, 4.0, 1.0, 0.1
1.5, 2.0, 2.0, 0.5, 0.1
W
1.5, 2.0, 2.0, 1.0, 0.2
1.5, 3.0, 3.0, 1.0, 0.3
1.5, 3.0, 4.0, 1.0, 0.3
1.5, 3.0, 3.0, 1.0, 0.2
S

OCTOBER

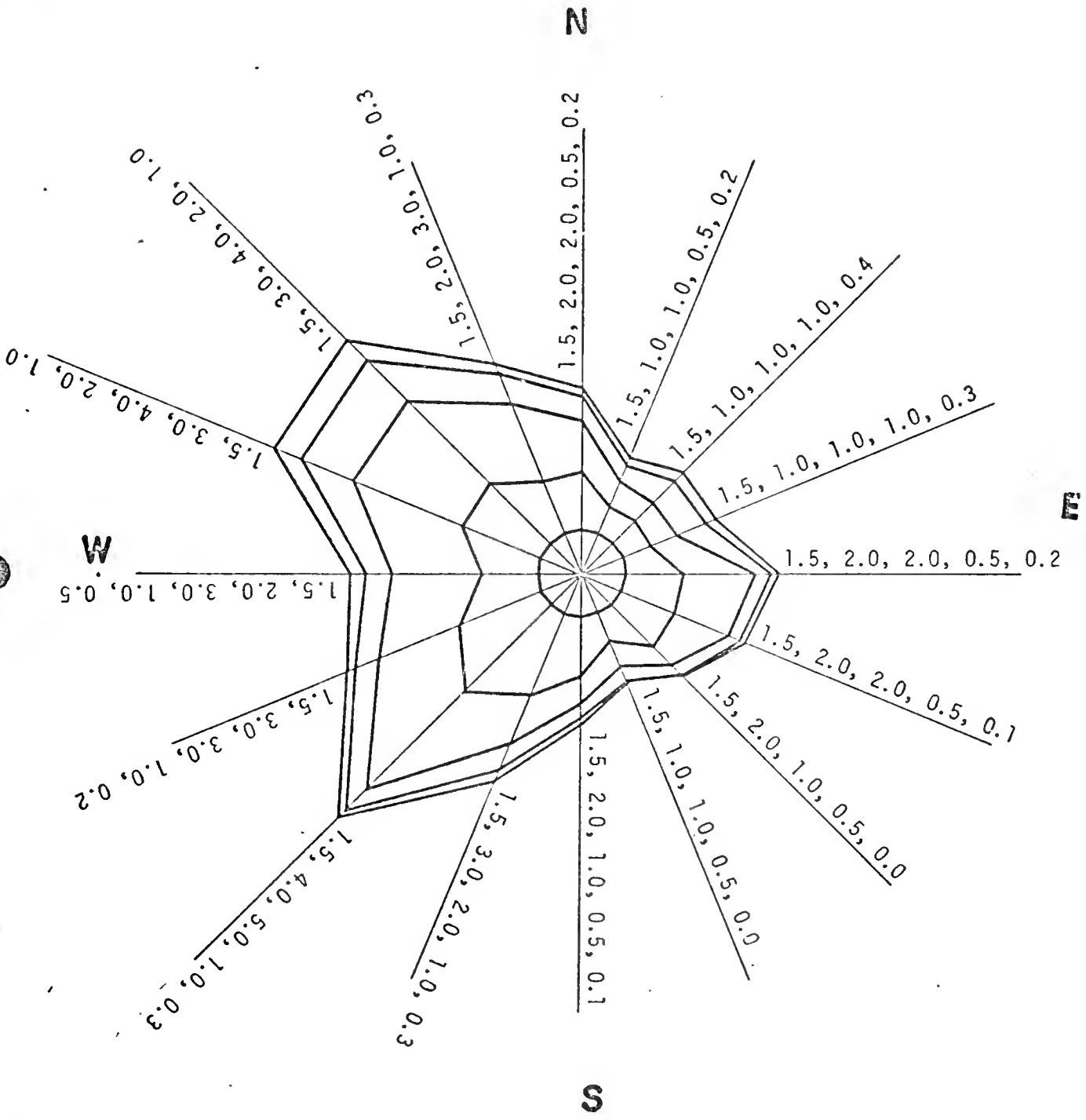

N
1.5, 2.0, 2.0, 0.5, 0.1
1.5, 1.0, 1.0, 0.5, 0.3
1.5, 1.0, 1.0, 0.5, 0.3
1.5, 1.0, 1.0, 1.0, 0.4
E
1.0, 1.0, 0.5, 0.5, 0.6
1.5, 1.0, 1.0, 0.5, 0.1
1.5, 1.0, 0.5, 0.5, 0.0
1.0, 1.0, 1.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.1
1.5, 3.0, 2.0, 1.0, 0.5
1.5, 3.0, 5.0, 2.0, 0.9
1.5, 3.0, 3.0, 1.0, 0.2
W
1.5, 3.0, 4.0, 2.0, 0.4
1.5, 3.0, 5.0, 2.0, 0.8
1.5, 4.0, 5.0, 2.0, 0.8
1.5, 2.0, 3.0, 1.0, 0.5
S

- NOVEMBER



N
E
S
W
1.5, 2.0, 2.0, 1.0, 0.2
1.5, 1.0, 1.0, 0.5, 0.3
1.0, 1.0, 0.5, 0.5, 0.3
1.0, 0.5, 0.5, 0.5, 0.3
1.0, 0.5, 1.0, 0.5, 0.3
1.0, 1.0, 0.5, 0.5, 0.2
1.0, 1.0, 1.0, 0.5, 0.1
1.5, 1.0, 0.5, 0.5, 0.1
1.5, 2.0, 1.0, 0.5, 0.1
1.5, 2.0, 2.0, 1.0, 0.3
1.5, 4.0, 6.0, 2.0, 0.4
1.5, 3.0, 5.0, 2.0, 0.3
1.5, 2.0, 4.0, 2.0, 0.7
1.5, 2.0, 5.0, 3.0, 1.6
1.5, 2.0, 5.0, 3.0, 1.6
1.5, 3.0, 5.0, 3.0, 1.6
1.5, 2.0, 4.0, 2.0, 0.4

DECEMBER


N
E
S
W
1.5, 2.0, 2.0, 0.5, 0.2
1.5, 1.0, 1.0, 0.5, 0.2
1.5, 1.0, 1.0, 1.0, 0.4
1.5, 1.0, 1.0, 1.0, 0.3
1.5, 2.0, 2.0, 0.5, 0.1
1.5, 2.0, 1.0, 0.5, 0.0
1.5, 1.0, 1.0, 0.5, 0.0
1.5, 2.0, 1.0, 0.5, 0.1
1.5, 3.0, 2.0, 1.0, 0.3
1.5, 4.0, 5.0, 1.0, 0.3
1.5, 3.0, 3.0, 1.0, 0.2
1.5, 2.0, 3.0, 1.0, 0.5
1.5, 3.0, 4.0, 2.0, 1.0
1.5, 3.0, 4.0, 2.0, 1.0
1.5, 2.0, 3.0, 1.0, 0.3

ANNUAL

Preliminary wind effects
Study of The Park Plaza, Boston

Park Plaza

APPENDIX B

PROBABILITY OF ANNUAL EXTREME WINDS IN BOSTON, MASSACHUSETTS*

Mean Recurrence Interval (Years)	25	50	100	200
Probability**	.96	.98	.99	.995

Height Above Ground (feet)	Speed (mph)			
30	76	84	92	102
100	90	100	109	120
200	99	110	120	132
300	104	117	127	141
400	109	121	132	147
500	112	125	138	151
600	116	129	141	155
700	118	131	143	159
800	121	134	147	162
900	122	136	148	163
1000	123	138	150	166

* Based on data from National Weather Records Center, Federal Building, Asheville, N. C., and computed using technique of Thom(1).

** Probability that the Annual Extreme Mile of wind will be less than the speed shown.

Definition of "Annual Extreme Mile" of wind (also called "Annual Fastest Mile"): The wind speed during the passage of the fastest mile of wind in a calendar year. A "mile of wind" can be thought of as a stream of air one mile long.

(1) H. C. S. Thom, American Society of Civil Engineers, Environmental Engineering Conference, Dallas, Texas 1967.

BOSTON PUBLIC LIBRARY
3 9999 06315 042 7